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U. S. Department of Agriculture
Soil Conservation Service
Engineering Division

Technical Release No. 35
February 1967

# UD METHOD OF RESERVOIR FLOOD ROUTING

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# THE UD METHOD OF RESERVOIR FLOOD ROUTING

The UD Method of Reservoir Flood Routing is based on a modification of M. M. Culp's parabolic relationship for outflow hydrographs (Technical Release No. 2 - Earth Spillways, 1956) and B-distribution dimensionless hydrographs as used by the Soil Conservation Service.

The method utilizes dimensionless charts for performing the routing of freeboard and emergency spillway hydrographs through reservoirs and provides a quick means of arriving at the proper proportioning of water impounding structures.

This Technical Release was prepared by Fredrick D. Theurer, Civil Engineer, with the particular assistance of C. Edwin Smith, Watershed Planning Specialist, and Gerald E. Oman, Design Engineer, and under the general direction of Harold M. Kautz, Head, Upper Darby Engineering and Watershed Planning Unit. The Fort Worth Engineering and Watershed Planning Unit and the Kentucky State office provided personnel and computer time to process data used in preparing and checking the charts.

## PART 1. GENERAL DESCRIPTION

### Introduction

A rapid but accurate method of routing the emergency spillway and freeboard storms through reservoirs is important to determine the least costly proportions for floodwater-retarding or multiple-purpose structures.

Many reservoir flood routing methods are available. However, each method has certain limitations. The graphical and storage-indication methods require several hours for each routing. The "shortcut" method described in Technical Release No. 2 requires a number of trial solutions. Electronic computer programs, although extremely fast when available, often require a day or two of delay in preparing and transferring data to and from the computer center.

To overcome these limitations, the UD Method makes it possible to obtain in a few minutes a direct solution to the basic flood routing equation, inflow is equal to outflow plus the change in storage. It provides a means of investigating combinations of emergency spillway widths and maximum water surface elevations for any given emergency spillway crest elevation. It also makes it possible for the engineer to examine the effect of:

1. The principal spillway system.

2. The emergency spillway layout and design.

3. The velocity at the control section of the emergency spillway.

4. The velocity in the exit channel of the emergency spillway.

5. The elevation of the emergency spillway crest.

The answers obtained by the UD Method have been checked by the graphical flood routing procedure for a large number of sites. The results of the cases tested agreed almost exactly with the answers obtained from the graphical method.

This release contains the theory, nomenclature, procedures, design charts, and examples of the Method. Work sheets are included to facilitate the flood routing computations.

## Description of Charts

### Reservoir Flood Routing Charts

Reservoir flood routing charts have been constructed for the emergency spillway and freeboard hydrographs given in NEH-4, Chapter 21, and are applicable for storms of any duration. Similar charts may be constructed for any unit hydrograph.

The curves are plots of the following dimensionless ratios:

1. The ratio of available flood storage at the emergency spillway crest elevation to the total volume of runoff - ($V_{sp}/V_I$).

2. The ratio of the available flood storage at the maximum water surface elevation to the total volume of runoff - ($V_{sw}/V_I$).

3. The ratio of the peak outflow rate to the peak inflow rate - ($Q_O/Q_I$).

Since the stage-storage information and inflow hydrograph are known for a particular site, by selecting an emergency spillway crest elevation and assuming a maximum water surface elevation the peak outflow rate can be determined directly from the charts.

### Emergency Spillway, Discharge Charts

The emergency spillway discharge charts given the stage-discharge relations for the emergency spillway for the following conditions:

1. Side slope (z:1) - for 0 to 3:1, in increments of 0.5:1.

2. Profile case - Entrance slope ($S_o$) for 0, -1, and -2 percent.

3. Entrance length (L) - for 0, 100, 150, 200, 300, and 500 feet.

4. Bottom width (b) - for 20 feet and greater.

5. Head ($H_p$) - for 0 to 26 feet.

Using this stage-discharge relationship and the peak outflow computed from the reservoir flood routing curves, the required emergency spillway bottom width can be solved directly.

## Emergency Spillway, Velocity Charts

The emergency spillway velocity charts are provided for the following conditions:

1. Manning's n values of 0.020 and 0.040.

2. Exit slope ($S_e$) - for 0.1 to 25 percent.

3. Discharge (Q/b) - for 0.05 to 200 cfs/ft.

4. Velocity ($V_e$) - for 1 to 30 fps.

The velocity at the control section and the minimum allowable exit channel slope corresponding to a discharge of 25 percent of the peak discharge also may be read from these charts.

## Effect of Structure Proportions on Reservoir Flood Routing

In any reservoir flood routing problem involving emergency spillway flow, there are only three major structure variables, in addition to the principal spillway system, which influence the final answer.

### Elevation of Emergency Spillway Crest ($E_e$)

Setting the elevation ($E_e$) establishes the amount of total storage ($V_{te}$) at the crest before the emergency spillway begins to operate. This total storage, less any unavailable storage ($V_{uf}$) is the amount of available flood storage ($V_{sp}$) at the crest.

### Maximum Water Surface Elevation ($E_w$)

This term is generally synonymous with the elevation of either the top of the dam or the design high water, depending upon the type of storm routed (freeboard or emergency spillway storm). The elevation ($E_w$) fixes the amount of total storage ($V_{tw}$) at this elevation. The storage ($V_{tw}$) less any unavailable storage, is the amount of available flood storage ($V_{sw}$) at elevation ($E_w$) and the amount of head ($H_p$) over the emergency spillway crest.

### Emergency Spillway Bottom Width (b)

The width (b) is a function of the discharge and the discharge per foot of bottom width. The discharge per foot of bottom width is a function of $H_p$ and the entrance length (L) for a given entrance slope or hydraulic profile case.

### Principal Spillway System

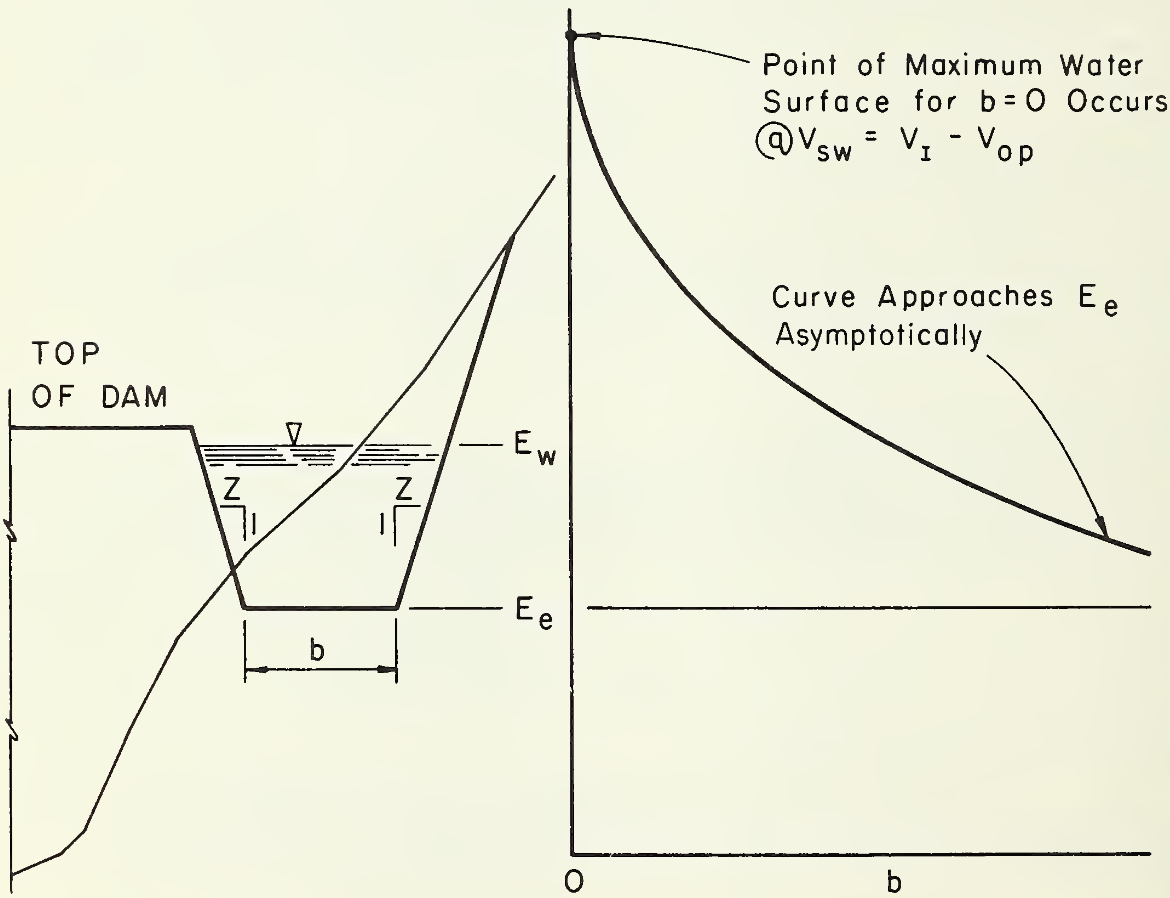
In routing the emergency and freeboard hydrographs through most reservoirs, the portion of principal spillway flow which precedes emergency spillway flow, has only a minor effect on the final results. The principal spillway flow ($V_{op}$), by delaying the time when the emergency spillway begins to flow,

slightly reduces the peak outflow ($Q_o$). It is a function of the average principal spillway release rate (or rates, if more than one stage), the corresponding available flood storage, and the dimensionless mass inflow curve.

The effect of principal spillway outflow ($V_{op}$) may be included in the UD Method of routing by adding it to $V_{sp}$ and $V_{sw}$. For routing purposes, the results are designated $V'_{sp}$ and $V'_{sw}$, respectively.

When the emergency spillway crest elevation is fixed and several maximum water surface elevations are assumed, corresponding emergency spillway bottom widths may be determined quickly by the UD Method. A curve may be plotted of the results which will completely define the range of $E_w$ versus b desired. Figure 1-1 illustrates the relation of $E_w$ and b for a typical site.

FIGURE 1-1




PROFILE ALONG ℄ OF DAM & CURVE OF $E_w$ vs b

## PART 2. NOMENCLATURE AND PROCEDURES

### Nomenclature

The nomenclature used in this technical release conforms as nearly as possible to existing nomenclature in other Soil Conservation Service documents. The various symbols were selected to suggest the meanings of the terms they represent. For example, $V_{te}$ means total volume of storage at the emergency spillway crest. To serve as a guide in understanding the symbols, a description of the meaning of the base letters and subscripts precede the definitions. Figures 2-1 and 2-2 further illustrate the nomenclature. Figure 2-1 relates the volume symbols to the storage pool and stage-storage curve. Figure 2-2 illustrates the relation of the volume and discharge rates to the mass and rate of flow hydrographs.

Only a small part of the following nomenclature is necessary for everyday computations. A complete listing, however, is needed for a full understanding of the theory and procedures.

#### Base Letters

| | |
|---|---|
| E | elevation |
| t | time |
| Q | rate of flow |
| V | volume |

#### Subscripts

| | |
|---|---|
| t | total storage |
| s | available storage |
| u | unavailable storage |
| $\ell$ | low stage |
| h | high stage |
| p | principal spillway system |
| e | emergency spillway |
| w | water surface |
| i,I | inflow |
| o,O | outflow |

#### Elevations

| | |
|---|---|
| $E_f$ | elevation of water surface after drawdown |
| $E_\ell$ | elevation of crest of low stage opening |
| $E_h$ | elevation of crest of high stage opening |
| $E_e$ | elevation of crest of emergency spillway |
| $E_w$ | elevation of maximum water surface during the passage of the inflow hydrograph |

Times

$t_\ell$ time of the beginning of the inflow hydrograph (generally at $E_\ell$)

$t_h$ time from beginning of inflow for the water surface to reach $E_h$

$t_e$ time from beginning of inflow for the water surface to reach $E_e$

$t_w$ time from beginning of inflow for the water surface to reach $E_w$

Rate of Flow

$Q_I$ maximum inflow rate

$Q_O$ maximum outflow rate (at $t_w$)

$Q_{p\ell}$ peak low stage release at $E_h$

$Q_\ell$ average low stage release rate

$Q_{ph}$ peak high stage release at $E_e$

$Q_h$ average high stage release rate

$Q_e$ emergency spillway release rate at $E_w$

Volumes

$V_I$ total volume of inflow (runoff)

$V_{o\ell}$ volume of outflow through the low stage spillway between $t_\ell$ and $t_h$

$V_{oh}$ volume of outflow through the high stage spillway between $t_h$ and $t_e$

$V_{op}$ volume of entire outflow through the principal spillway system between $t_\ell$ and $t_e$

$V_{oe}$ volume of outflow through combined principal spillway system and emergency spillway between $t_e$ and $t_w$

$V_{t\ell}$ volume of total storage at $E_\ell$

$V_{th}$ volume of total storage at $E_h$

$V_{te}$ volume of total storage at $E_e$

$V_{tw}$ volume of total storage at $E_w$

$V_{s\ell}$ volume of available flood storage between $E_h$ and $E_\ell$ ($V_{th}-V_{uf}$)

$V_{sh}$ volume of available flood storage between $E_e$ and $E_h$ ($V_{te}-V_{th}$) for two stage; ($V_{te}-V_{uf}$) for single stage

$V_{sp}$ volume of available flood storage between $E_e$ and $E_\ell$ ($V_{te}-V_{uf}$ or $V_{s\ell} + V_{sh}$)

$V_{se}$ volume of available flood storage between $E_w$ and $E_e$ ($V_{tw}-V_{te}$)

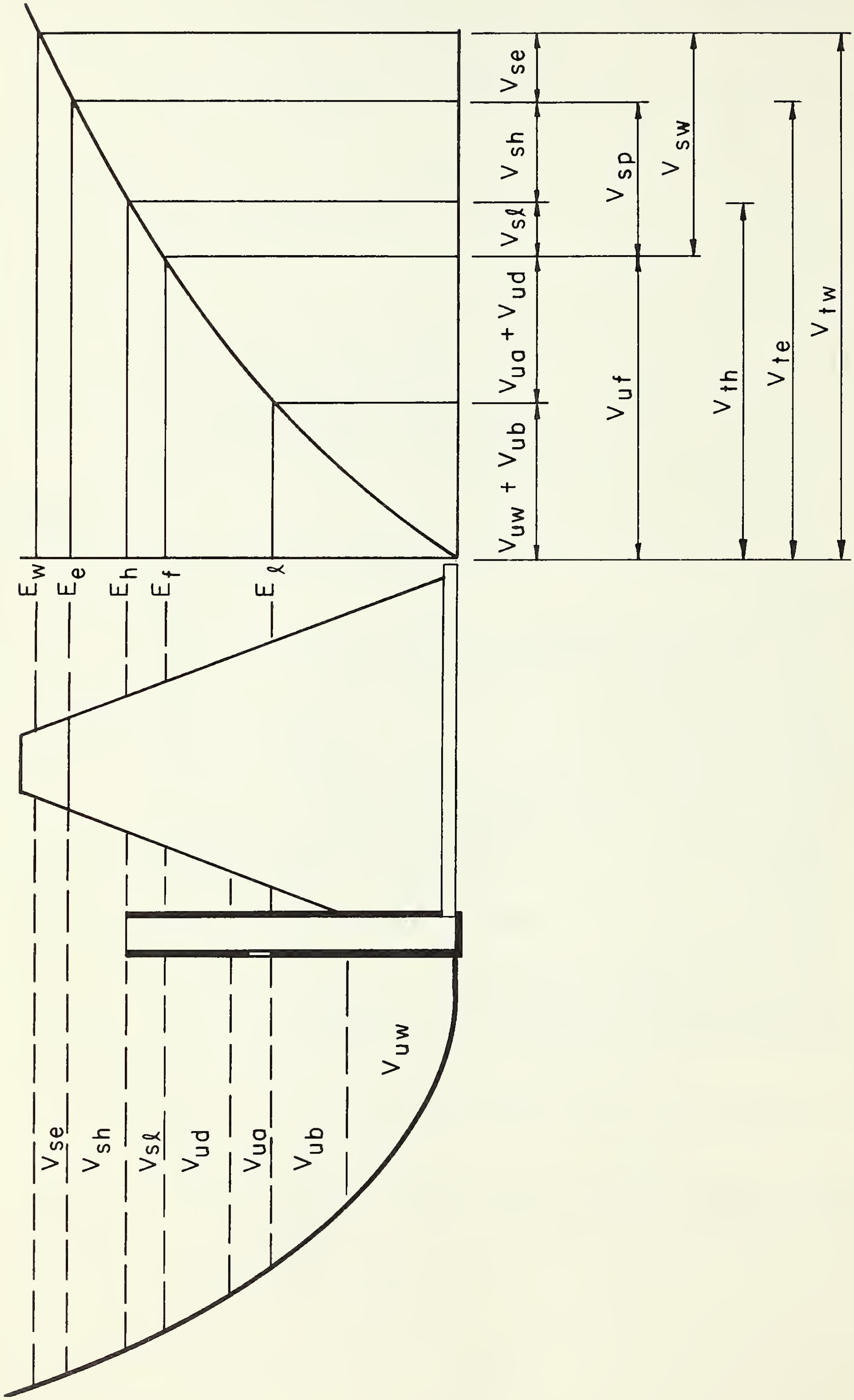
$V_{sw}$ volume of available flood storage between $E_w$ and $E_\ell$ ($V_{tw}-V_{uf}$ or $V_{sp} + V_{se}$)

| | |
|---|---|
| $V'_{s\ell}$ | volume of available flood storage at $E_h$ plus entire outflow through the principal spillway system during the time $t_h$ ($V'_{s\ell} = V_{s\ell} + V_{o\ell}$) |
| $V'_{sp}$ | volume of available flood storage at $E_e$ plus entire outflow through the principal spillway system during the time $t_e$ ($V'_{sp} = V_{sp} + V_{op}$) |
| $V'_{sw}$ | volume of available flood storage at $E_w$ plus entire outflow through the principal spillway system during the time $t_e$ ($V'_{sw} = V_{sw} + V_{op}$) |
| $V_{uw}$ | Wet sediment storage |
| $V_{ua}$ | Aerated sediment storage |
| $V_{us}$ | total sediment storage (wet plus aerated) unavailable for flood routing |
| $V_{ub}$ | beneficial storage unavailable for flood routing |
| $V_{ud}$ | flood prevention storage unavailable for flood routing due to drawdown time limitations |
| $V_{uf}$ | total unavailable storage for flood routing ($V_{uf} = V_{us} + V_{ub} + V_{ud}$) |

Emergency Spillway

| | |
|---|---|
| b | bottom width of emergency spillway |
| $H_p$ | head over emergency spillway crest ($E_w$-$E_e$) |
| L | length of emergency spillway entrance channel. (Adverse and level sections) |
| $S_o$ | slope of entrance channel emergency spillway |
| $S_e$ | slope of exit channel emergency spillway |
| $v_c$ | critical velocity at the control section of the emergency spillway |
| $v_e$ | velocity in the exit channel of the emergency spillway assuming uniform flow |
| z | emergency spillway side slope |
| Case | emergency spillway profile type, see ES-124 |

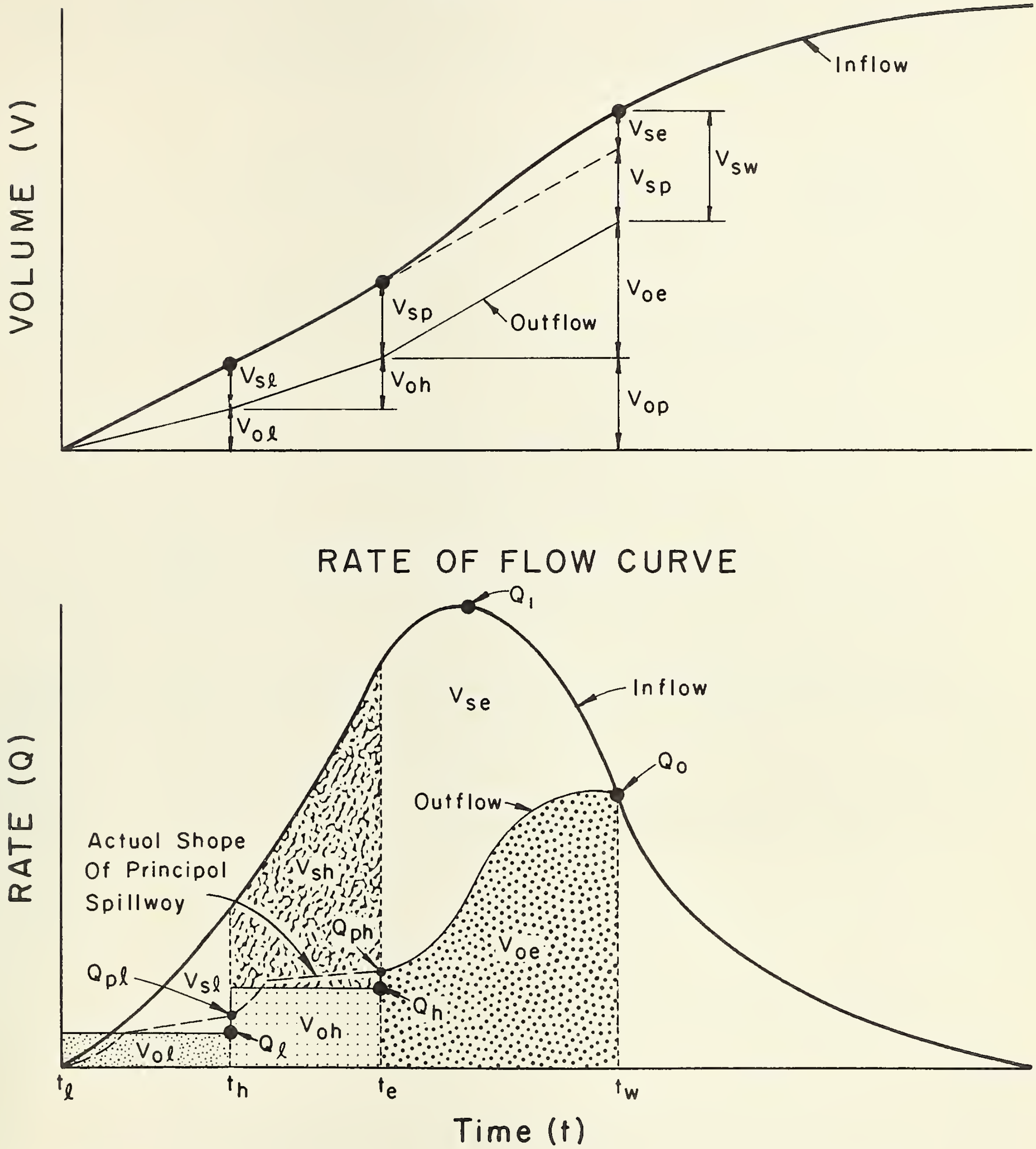
FIGURE 2-1




PROFILE THROUGH RESERVOIR & STAGE STORAGE CURVE

FIGURE 2-2

## MASS CURVE




WHERE:

$V_{sp} = V_{s\ell} + V_{sh}$

$V_{sw} = V_{sp} + V_{se}$

$V_{op} = V_{o\ell} + V_{oh}$

$V_{oe} = KQ_o\,(t_w - t_e)$

$V'_{s\ell} = V_{s\ell} + V_{o\ell}$

$V'_{sw} = V_{sw} + V_{op}$

$V'_{sp} = V_{sp} + V_{op}$

## Procedures

Detailed step procedures are given to make full use of this method. After becoming familiar with the principles involved, the designer will find that the detailed procedures are no longer needed for routine calculations. These procedures are based on the theory given in Part 4.

### UD Method Work Sheet

1. Site Data:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| State ____________ | | Watershed ______________ | | | Site ____________ | | |
| Class ________ | $V_{us}$ = _____ AF | | $V_{ub}$ = _____ AF | | $V_{ud}$ = _____ AF | | $V_{uf}$ = _____ AF |

a. Fill out location data

b. List class of structure

c. List total sediment storage, $V_{us}$

d. Compute total beneficial storage

$V_{ub}$ = Recreation + Water Supply + Irrigation Storages

e. List the total unavailable storage for flood routing, $V_{uf}$

2. Inflow Hydrograph Data:

| | | | |
|---|---|---|---|
| Storm __________ | D.A. ________ $mi^2$ | Runoff ________ in. | $Q_I$ = ____________ cfs |
| Hydrograph Family _____ | $T_o/T_p$ _____ | $V_I$ = 53.33 x Runoff x D.A. = | _______ AF |

a. Fill out information from SCS-319

b. Compute the total volume of runoff

$V_I$ = 53.33 x Runoff (inches) x Drainage Area (square miles)

3. Low Stage Calculations (necessary for two stage structures only):

| | | | |
|---|---|---|---|
| $Q_\ell$ = _____ cfs | $E_h$ = ____________ ft | $V_{s\ell}$ = __________ AF | $V'_{s\ell}/V_I$ = _______ |
| $Q_\ell/Q_I$ = _______ | $V_{th}$ = ____________ AF | $V_{s\ell}/V_I$ = __________ | $V_{o\ell}/V_I$ = _______ |

a. Obtain the average low stage release rate, $Q_\ell$

b. Obtain the elevation of the high stage opening, $E_h$

c. Read the total storage at $E_h$ from the stage-storage curve, this is $V_{th}$

d. Compute the available flood storage at $E_h$

d. Compute the available flood storage at $E_h$

$V_{s\ell} = V_{th} - V_{uf}$

e. Follow steps 1 through 5 of the procedure given under principal spillway corrections for two stage structures

4. <u>Principal Spillway System Calculations</u>:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $E_e$ = ______ | ft | z = ______ | | L = ____ | ft | | $V_{sp}/V_I$ = | ______ |
| $V_{te}$ = ______ | AF | Case ______ | | $S_o$ = ____ | % | $V_{sp}/V_I + V_{o\ell}/V_I$ = | ______ |
| $V_{sp}$ = ______ | AF | $Q_h$ = ______ | cfs | | | $V'_{sp}/V_I$ = | $\boxed{\phantom{xx}}$ |
| $Q_{ph}$ = ______ | cfs | $Q_h/Q_I$ = ____ | | | | $V_{op}/V_I$ = | ______ |

a. Select an elevation of emergency spillway crest, $E_e$

b. Read the total storage at $E_e$ from the stage-storage curve, this is $V_{te}$

c. Compute the available flood storage at $E_e$
$V_{sp} = V_{te} - V_{uf}$

d. Obtain principal spillway discharge at $E_e$, this is $Q_{ph}$

e. Compute the average high stage release rate, this is $Q_h$

f. Follow the procedure given for single stage structures, or steps 6 through 10 for two stage structures, principal spillway corrections

g. Compute the principal spillway correction

$V_{op}/V_I = V'_{sp}/V_I - V_{sp}/V_I$

h. Obtain from the emergency spillway layout data

(1) Entrance Length, L

(2) Profile case

(3) Entrance slope, $S_o$

(4) Side slopes, z

5. <u>Routing</u>:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $E_w$ ft | $V_{tw}$ AF | $V_{sw}$ AF | $V_{sw}/V_I$ | $V'_{sw}/V_I$ | $Q_o/Q_I$ | $Q_o$ cfs | $Q_e$ cfs | $H_p$ ft | $Q_e/b$ | b ft | v fps |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

a. Col. 1 - Assume a maximum water surface elevation, $E_w$

b. Col. 2 - Read the total storage at $E_w$, this is $V_{tw}$

c. Col. 3 - Compute the available flood storage at $E_w$

$$V_{sw} = V_{tw} - V_{uf}$$

d. Col. 4 - Compute $V_{sw}/V_I$

e. Col. 5 - Compute $V'_{sw}/V_I = V_{sw}/V_I + V_{op}/V_I$

f. Col. 6 - Read $Q_O/Q_I$ from proper routing chart using the coordinates of $V'_{sp}/V_I$ and $V'_{sw}/V_I$ (this step performs the routing)

g. Col. 7 - Compute the maximum total outflow

$$Q_O = (Q_I) \times (Q_O/Q_I)$$

h. Col. 8 - Compute the peak outflow through the emergency spillway

$$Q_e = Q_O - Q_p$$

i. Col. 9 - Compute the head over the emergency spillway crest

$$H_p = E_w - E_e$$

j. Col. 10 - Read the discharge per foot of bottom width (Q/b) for the $H_p$ from the charts provided in Part 6

k. Col. 11 - Compute the emergency spillway bottom width

$$b = \frac{Q_e}{Q/b}$$

l. Col. 12 - Read the velocity at the control section or in the exit channel from the emergency spillway hydraulics, ES-600

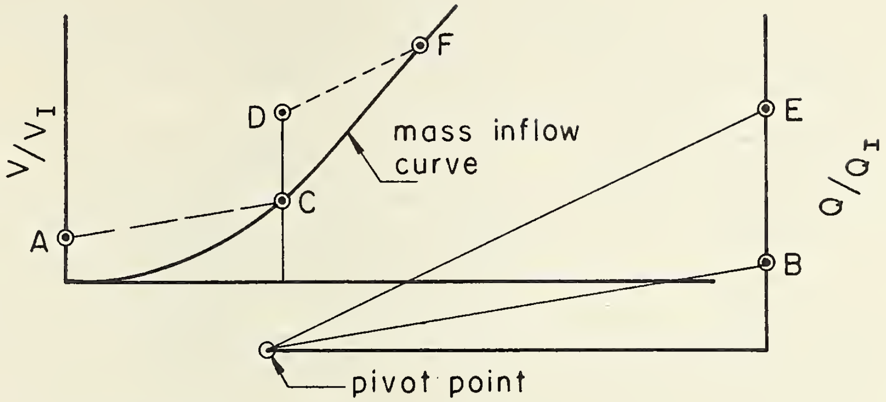
6. Graph:

a. If more than one routing is necessary to cover the desired range of $E_e$, $E_w$, b, and v, then repeat the previous steps 5a through 5ℓ for two or more $E_w$ and/or $E_e$

b. Plot $E_w$ versus b for each $E_e$ selected. Generally 4 feet to the inch for $E_w$ and from 40 to 100 feet to the inch for b will give satisfactory results. Values for intermediate $E_e$ may be interpolated

c. Plot v versus b for each $E_e$ selected (only when needed)

Principal Spillway Correction




1. Single-Stage Principal Spillway

   a. Compute $V_{sp}/V_I$, this is point A

   b. Compute $Q_h/Q_I$, this is point B

   c. Project slope of line (pivot point to point B) to point A and intersect mass inflow curve, this is point C

   d. Read $V/V_I$ at point C, this is $V'_{sp}/V_I$

2. Two-Stage Principal Spillway

   a. Compute $V_{s\ell}/V_I$, this is point A

   b. Compute $Q_\ell/Q_I$, this is point B

   c. Project slope of line (pivot point to point B) to point A and intersect mass inflow curve, this is point C

   d. Read $V/V_I$ at point C, this is $V'_{s\ell}/V_I$

   e. Compute $V_{o\ell}/V_I = V'_{s\ell}/V_I - V_{s\ell}/V_I$

   f. Compute $V_{sp}/V_I$

   g. Add $V_{o\ell}/V_I$ to $V_{sp}/V_I$, this is point D

   h. Compute $Q_h/Q_I$, this is point E

   i. Project slope of line (pivot point to point E) to point D and intersect mass inflow curve, this is point F

   j. Read $V/V_I$ at point F, this is $V'_{sp}/V_I$

Reservoir Flood Routing Charts

The reservoir flood routing charts reflect the individual characteristics of each design hydrograph present in table 21.17, Chapter 21, National Engineering Handbook 4. Separate drawing numbers are assigned to each hydrograph family as follows:

| Hydrograph Family | ES Drawing No. |
|---|---|
| 1 | ES-601 |
| 2 | ES-602 |
| 3 | ES-603 |
| 4 | ES-604 |
| 5 | ES-605 |

A separate sheet is used for each $T_o/T_p$ ratio as follows:

| $T_o/T_p$ | 1 | 1.5 | 2 | 3 | 4 | 6 | 10 | 16 | 25 | 36 | 50 | 75 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sheet No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |

Since hydrograph families 4 and 5 do not have a $T_o/T_p$ ratio of 75, there is no sheet 12 for ES-604 and 605.

The charts give a direct solution to equation 4-7:

$$V'_{sw}/V_I = V_{iw}/V_I - K\ Q_o/Q_I\ [t_w\ (Q_I/V_I) - t_e\ (Q_I/V_I)]$$

In performing a reservoir routing, the only information needed is:

1. Storage to the emergency spillway crest ($V_{sp}$)

2. Storage to the maximum water surface elevation ($V_{sw}$)

3. Principal spillway correction ($V_{op}$), if necessary

The ratio of total peak outflow to peak inflow ($Q_o/Q_I$) can be read directly from the charts.

Emergency Spillway Hydraulics

The emergency spillway hydraulics charts have been calculated using current Service methods and criteria. The discharge chart values have been determined by computing water surface profiles. Portions of ES-124 through ES-131 have been used in the analysis. The velocity chart values are based on the assumption that the flow is confined in a rectangular channel having a bottom width (b) and frictionless side walls.

Discharge Charts

These charts are arranged to give direct solutions for the stage-discharge relationship of emergency spillways for profile case 2. The charts are separated for each side slope according to the following table:

| Side Slope (z) | 0 | 1/2 | 1 | 1-1/2 | 2 | 2-1/2 | 3 |
|---|---|---|---|---|---|---|---|
| ES Drawing No. | ES-606 | ES-607 | ES-608 | ES-609 | ES-610 | ES-611 | ES-612 |

Sheet 1 of each drawing gives the $H_p$ versus Q/b values for bottom widths greater than 100 feet when $H_p$ is greater than 2 feet and for all bottom widths when $H_p$ is less than 2 feet. These values are available both in curve and tabular form. Sheets 2 and 3 of each drawing give the $H_p$ versus Q values for the remaining conditions. The following table is a guide to selecting the proper sheet:

| $H_p$ | b | Use Sheet No. |
|---|---|---|
| $0 \leq H_p \leq 2.0'$ | All | 1 |
| $2.0' < H_p \leq 26.0'$ | $b \geq 100'$ | 1 |
| $2.0' < H_p \leq 26.0'$ | $20' \leq b < 100'$ | 2 and 3 |

By using the curves in ES-613, the results obtained from the other emergency spillway hydraulic charts may be modified to provide stage-discharge relationship for the following two entrance conditions:

1. $S_o = 0$
2. $S_o = 1$ percent with a 30-foot level section

The correction to obtain the proper value for $H_p$ can be made by using the following procedure:

1. Assume $S_o = 2$ percent
2. Read corresponding $H_p$ from the proper drawing (ES-606 through ES-612)
3. Read $\Delta H_p$ from ES-613
4. Add $H_p$ from step 2 to $\Delta H_p$ from step 3. This is the actual $H_p$ for the given entrance condition

Velocity Charts

These charts give a direct solution for emergency spillway velocities and exit channel slopes. Charts are given for n = 0.020 and 0.040. On these charts are curves for r = 1.0 and 0.25, where r is equal to the ratio of any given discharge to the peak discharge. The curve r = 0.25 is for use in determining the minimum exit channel slope. The curve r = 1.0 is for use in determining the velocity at the control section.

The procedures for the use of the velocity charts are as follows:

1. Velocity in the exit channel ($V_e$) - Read $V_e$ directly from the chart for the proper value of n.

2. Velocity at the control section ($V_c$) - Read $V_c$ directly from the proper chart using r = 1.0.

3. Minimum exit channel slope ($S_e$) - Locate the intersection of the Q/b curve with the r = 0.25 curve and read the corresponding value of $S_e$.

4. Maximum discharge per foot of bottom width (Q/b) for a given allowable velocity in the exit channel - Locate a point on the <u>r = 0.25</u> curve for the given value of $V_e$. Read the corresponding value of Q/b. This is the <u>peak</u> discharge per foot of bottom width.

## Example No. 1 - Without Principal Spillway Correction

Purpose: This example illustrates the UD Method of reservoir flood routing excluding the principal spillway correction.

Given:

1. Site Data

| | | |
|---|---|---|
| State Pa. | Watershed Greene-Dreher | Site PA-446 |
| Class (c) | $V_{us}$ = ____ AF  $V_{ub}$ = ____ AF  $V_{ud}$ = ____ AF | $V_{uf}$ = 70 AF |

2. Inflow hydrograph data (SCS-319) - See Chapter 21, NEH-4

| | | | |
|---|---|---|---|
| Storm Freeboard | D.A. 4.80 $mi^2$ | Runoff 19.4 in. | $Q_I$ = 15,572 cfs |
| Hydrograph Family 2 | $T_o/T_p$ 3 | $V_I$ = 53.33 x Runoff x D.A. = ____ AF | |

3. First stage information - Neglect principal spillway correction

4. Emergency spillway layout data, associated principal spillway discharge, and total storage to the emergency spillway crest.

| | | | |
|---|---|---|---|
| $E_e$ = 1822.0 ft | z = 2 | L = 200 ft | $V_{sp}/V_I$ = ____ |
| $V_{te}$ = 1000 AF | Case 2 | $S_o$ = 2 % | $V_{sp}/V_I + V_{o\ell}/V_I$ = ____ |
| $V_{sp}$ = ____ AF | $Q_h$ = ____ cfs | | $V'_{sp}/V_I$ = ____ |
| $Q_{ph}$ = 200 cfs | $Q_h/Q_I$ = ____ | | $V_{op}/V_I$ = ____ |

5. Desired maximum water surface elevations and associated total storages.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $E_w$ | $V_{tw}$ | $V_{sw}$ | $V_{sw}/V_I$ | $V'_{sw}/V_I$ | $Q_o/Q_I$ | $Q_o$ | $Q_e$ | $H_p$ | $Q_e/b$ | b | v |
| ft | AF | AF | | | | cfs | cfs | ft | | ft | fps |
| 1828.0 | 1370 | | | | | | | | | | |
| 1828.5 | 1400 | | | | | | | | | | |
| 1829.0 | 1440 | | | | | | | | | | |
| 1830.0 | 1510 | | | | | | | | | | |
| 1831.0 | 1590 | | | | | | | | | | |
| 1832.0 | 1670 | | | | | | | | | | |

Required:

Route the given freeboard storm through the structure to obtain a curve of required emergency spillway width versus given heights of dam (maximum water surface elevation) and a curve of the velocity in the exit channel.

Procedure:

Use work sheet and follow procedure in Part 2.

Solution:

1. Record given data directly on the work sheet as shown.

2. Compute the volume of runoff in acre-feet:

$$V_I = 53.33 \text{ x Runoff in inches x Drainage area in square miles}$$

$$= 53.33 \text{ x } 19.4 \text{ x } 4.80$$

$$= 4966 \text{ AF}$$

3. Compute the available flood storage to the emergency spillway crest:

$$V_{sp} = V_{te} - V_{uf}$$

$$= 1000 - 70$$

$$= 930 \text{ AF}$$

4. Compute $V'_{sp}/V_I$: ($V_{op}/V_I = 0$, results from neglecting principal spillway correction)

$$V'_{sp}/V_I = V_{sp}/V_I + V_{op}/V_I$$

$$= (930/4966) + 0$$

$$= 0.187$$

5. Follow steps 5-a through 5-ℓ of the procedure given in Part 2.

<u>Sample Calculation for $E_w$ = 1828.0'</u>

(Using columns listed on work sheet)

Col. 1 As listed
Col. 2 As listed
Col. 3 $V_{sw} = V_{tw} - V_{uf}$
$= 1370 - 70$
$= 1300$ AF
Col. 4 Omit

Col. 5 $V'_{sw}/V_I = V_{sw}/V_I + V_{op}/V_I$
$= 1300/4966 + 0$
$= 0.262$

Col. 6 $Q_0/Q_I = 0.955$ — ES-602, sheet 4

Col. 7 $Q_0 = Q_I \times (Q_0/Q_I)$
$= 15,572 \times 0.955$
$= 14,870$ cfs

Col. 8 $Q_e = Q_0 - Q_{ph}$
$= 14,870 - 200$
$= 14,670$ cfs

Col. 9 $H_p = E_w - E_e$
$= 1828.0 - 1822.0$
$= 6.0'$

Col. 10 $Q_e/b = 40.7$ cfs/ft — ES-610, sheet 1

Col. 11 $b = Q_e \div (Q_e/b)$
$= 14,670/40.7$
$= 360'$

Col. 12 $V_e = 12.0$ fps — ES-600, sheet 1

6. Plot the top of dam ($E_w$) versus the emergency spillway bottom width (b).

7. Plot the velocity in the exit channel ($V_e$) versus the emergency spillway bottom width (b).

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

# U D METHOD OF RESERVOIR FLOOD ROUTING

By: FOV Date: 6/66
Ck: B.J.G. Date: 6/66

State PENNA Watershed GREENE - DREHER Site PA-446

Class C $V_{us}$ = 50 AF $V_{ub}$ = 0 AF $V_{ud}$ = 20 AF $V_{uf}$ = 70 AF

Storm FREEBOARD D.A. 4.80 mi$^2$ Runoff 19.4 in. $Q_I$ = 15,572 cfs

Hydrograph Family 2 $T_a/T_p$ 3 $V_I$ = 53.33 x Runoff x D.A. = 4966 AF

$Q_\ell$ = – cfs $E_h$ = – ft $V_{s\ell}$ = – AF $V'_{s\ell}/V_I$ = –

$Q_\ell/Q_I$ = – $V_{th}$ = – AF $V_{s\ell}/V_I$ = – $V_{o\ell}/V_I$ = SINGLE STAGE

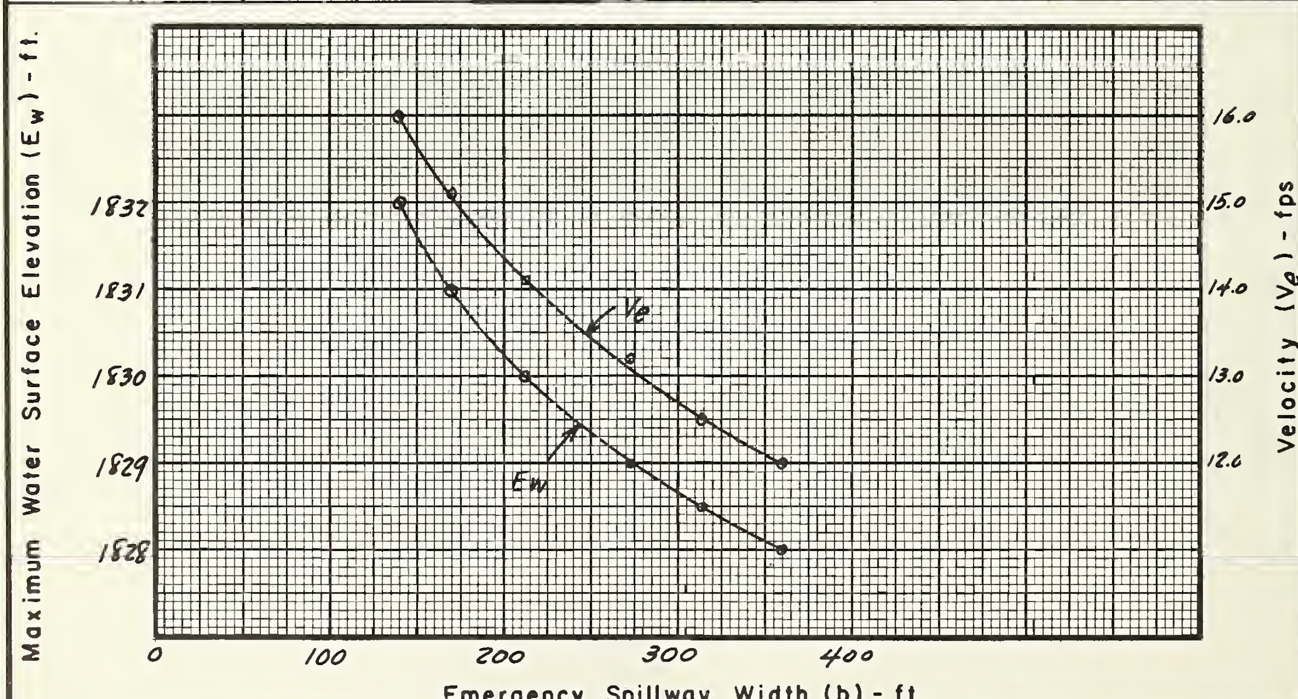
$E_e$ = 1822.0 ft z = 2 L = 200 ft $V_{sp}/V_I$ = –

$V_{te}$ = 1000 AF Case 2 $S_a$ = 2 % $V_{sp}/V_I + V_{a\ell}/V_I$ = –

$V_{sp}$ = 930 AF $Q_h$ = – cfs $V'_{sp}/V_I$ = $\boxed{0.187}$

$Q_{ph}$ = 200 cfs $Q_h/Q_I$ = – $V_{ap}/V_I$ = 0 (ASSUMED)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $E_w$ ft | $V_{tw}$ AF | $V_{sw}$ AF | $V_{sw}/V_I$ | $V'_{sw}/V_I$ | $Q_O/Q_I$ | $Q_O$ cfs | $Q_e$ cfs | $H_p$ ft | $Q_e/b$ | b ft | $v_e$ fps |
| 1828.0 | 1370 | 1300 | | 0.262 | 0.955 | 14,870 | 14,670 | 6.0 | 40.7 | 360 | 12.0 |
| 1828.5 | 1400 | 1330 | | 0.268 | 0.950 | 14,790 | 14,590 | 6.5 | 46.5 | 314 | 12.5 |
| 1829.0 | 1440 | 1370 | | 0.276 | 0.940 | 14,640 | 14,440 | 7.0 | 53.0 | 272 | 13.2 |
| 1830.0 | 1510 | 1440 | | 0.290 | 0.920 | 14,330 | 14,130 | 8.0 | 66.5 | 212 | 14.1 |
| 1831.0 | 1590 | 1520 | | 0.306 | 0.900 | 14,010 | 13,810 | 9.0 | 81.2 | 170 | 15.1 |
| 1832.0 | 1670 | 1600 | | 0.322 | 0.880 | 13,700 | 13,500 | 10.0 | 97.0 | 139 | 16.0 |



Example No. 2 - With Principal Spillway Correction

Purpose: This example illustrates the UD Method of reservoir flood routing including the principal spillway correction for a single stage structure. For two stage structures, the procedure is similar.

Given:

1. Site Data

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| State Pa. | | Watershed Greene-Dreher | | Site PA-446 | | | |
| Class (c) | $V_{us}$ = ____ AF | | $V_{ub}$ = ____ AF | | $V_{ud}$ = ____ AF | | $V_{uf}$ = 70 AF |

2. Inflow hydrograph data (SCS-319 - see page

| | | | | |
|---|---|---|---|---|
| Storm Em. Sp. | D.A. 4.80 $mi^2$ | Runoff 10.3 in. | $Q_I$ = 8499 cfs | |
| Hydrograph Family 1 | $T_o/T_P$ 3 | $V_I$ = 53.33 x Runoff x D.A. = ____ AF | | |

3. First stage information - not applicable for single stage structure.

4. Emergency spillway layout data and associated principal spillway discharge.

| | | | |
|---|---|---|---|
| $E_e$ = 1822.0 ft | z = 2 | L = 200 ft | $V_{sp}/V_I$ = |
| $V_{te}$ = 1000 AF | Case 2 | $S_o$ = 2 % | $V_{sp}/V_I + V_{o\ell}/V_I$ = |
| $V_{sp}$ = ____ AF | $Q_h$ = ____ cfs | | $V'_{sp}/V_I$ = |
| $Q_{ph}$ = 200 cfs | $Q_h/Q_I$ = ____ | | $V_{op}/V_I$ = |

5. Desired maximum water surface elevations and associated total storages.

| 1<br>$E_w$<br>ft | 2<br>$V_{tw}$<br>AF | 3<br>$V_{sw}$<br>AF | 4<br>$V_{sw}/V_I$ | 5<br>$V'_{sw}/V_I$ | 6<br>$Q_O/Q_I$ | 7<br>$Q_O$<br>cfs | 8<br>$Q_e$<br>cfs | 9<br>$H_p$<br>ft | 10<br>$Q_e/b$ | 11<br>b<br>ft | 12<br>v<br>fps |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1825.0 | 1190 | | | | | | | | | | |
| 1825.5 | 1220 | | | | | | | | | | |
| 1826.0 | 1250 | | | | | | | | | | |
| 1826.5 | 1280 | | | | | | | | | | |
| 1827.0 | 1310 | | | | | | | | | | |
| 1827.5 | 1340 | | | | | | | | | | |

Required:

Route the given emergency spillway storm through the structure to obtain a curve of required emergency spillway width versus given Design High Water elevations (maximum water surface) and a curve of the velocity in the exit channel.

Procedure:

Use work sheet and follow procedure given in Part 2.

Solution:

1. Record given data directly on the work sheet as shown.

2. Compute the volume of runoff in acre-feet:

$$V_I = 53.33 \times \text{Runoff in inches} \times \text{Drainage area in square miles}$$

$$= 53.33 \times 10.3 \times 4.80$$

$$= 2637 \text{ AF}$$

3. Compute the available flood storage to the emergency spillway crest:

$$V_{sp} = V_{te} - V_{uf}$$

$$= 1000 - 70$$

$$= 930 \text{ AF}$$

4. Compute the average high stage release rate:

$$Q_h = 0.9\ Q_{ph}$$

$$= 0.9 \times 200$$

$$= 180 \text{ cfs}$$

5. Follow steps 1 through 4 of the procedure given in Part 2.

a. $V_{sp}/V_I = 930/2637$

$= 0.353$

b. $V_{o\ell}/V_I + V_{sp}/V_I = 0 + 0.353$

$= 0.353$

c. $Q_h/Q_I = 180/8499$

$= 0.021$

d. $V'_{sp}/V_I = 0.375$ - Graphical solution from ES-601, sheet 4.

6. Compute the amount of outflow through the principal spillway system prior to emergency spillway flow:

$$V_{op}/V_I = V'_{sp}/V_I - V_{sp}/V_I$$

$$= 0.375 - 0.353$$

$$= 0.022$$

7. Follow steps 5-a through 5-$\ell$ of the procedure given in Part 2.

Sample Calculations for $E_w = 1825.0'$

(Using columns listed on work sheet)

Col. 1 As listed

Col. 2 As listed

Col. 3 $V_{sw} = V_{tw} - V_{uf}$
$= 1190 - 70$
$= 1120$ AF

Col. 4 $V_{sw}/V_I = 1120/2637$
$= 0.425$

Col. 5 $V'_{sw}/V_I = V_{sw}/V_I + V_{op}/V_I$
$= 0.425 + 0.022$
$= 0.447$

Col. 6 $Q_0/Q_I = 0.840$ ES-601, sheet 4

Col. 7 $Q_0 = Q_I \times (Q_0/Q_I)$
$= 8499 \times 0.840$
$= 7140$ cfs

Col. 8 $Q_e = Q_0 - Q_{ph}$
$= 7140 - 200$
$= 6940$ cfs

Col. 9 $H_p = E_w - E_e$
$= 1825.0 - 1822.0$
$= 3.0'$

Col. 10 $Q_e/b = 12.3$ cfs/ft ES-610, sheet 1

Col. 11 $b = Q_e \div (Q_e/b)$
$= 6940/12.3$
$= 564'$

Col. 12 $V_e = 8.0$ fps ES-600, sheet 1

8. Plot the Design High Water ($E_W$) versus the emergency spillway bottom width (b).

9. Plot the velocity in the exit channel ($V_e$) versus the emergency spillway bottom width (b).

SCS-148
10/66

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

# U D METHOD OF RESERVOIR FLOOD ROUTING

By: FDT Date: 6/66
Ck: B.J.G. Date: 6/66

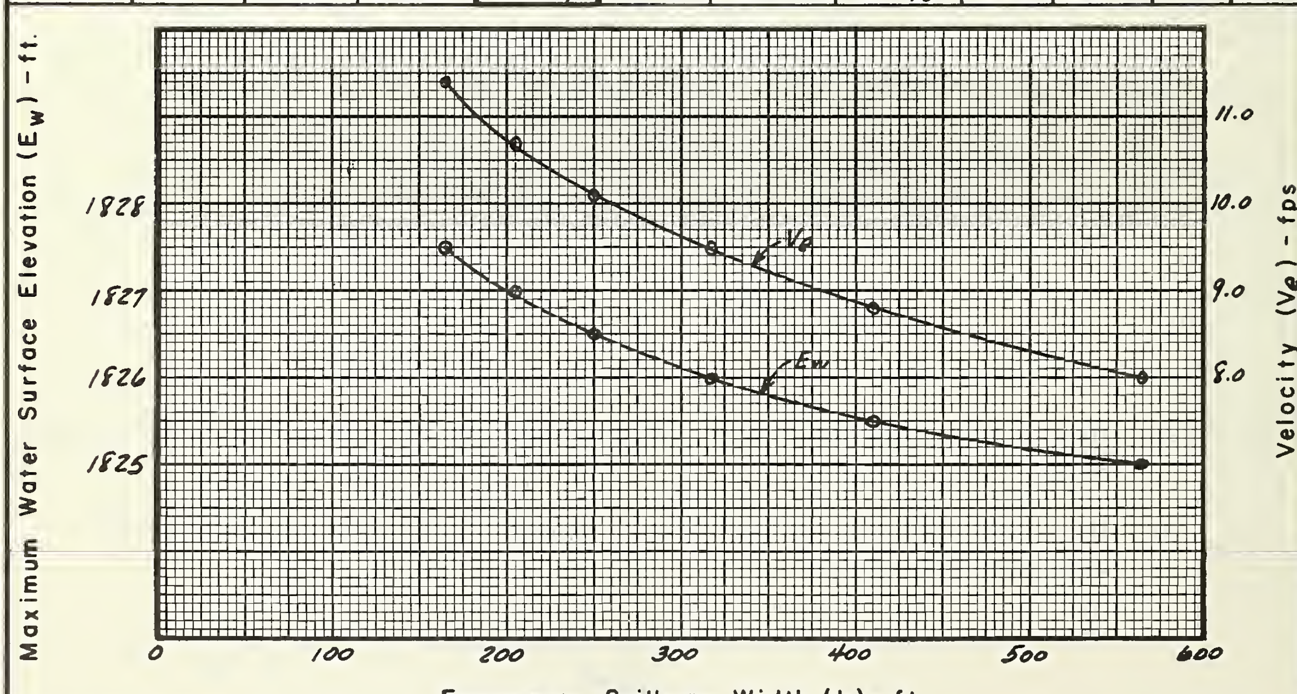
State PENNA. Watershed GREENE- DREHER Site PA- 446
Class C $V_{us}$ = 50 AF $V_{ub}$ = 0 AF $V_{ud}$ = 20 AF $V_{uf}$ = 70 AF

Storm EMERG. SPWY. D.A. 4.80 $mi^2$ Runoff 10.3 in. $Q_I$ = 8499 cfs
Hydrograph Family 1 $T_o/T_p$ 3 $V_I$ = 53.33 x Runoff x D.A. = 2637 AF

$Q_\ell$ = – cfs $E_h$ = – ft $V_{s\ell}$ = – AF $V'_{s\ell}/V_I$ = –
$Q_\ell/Q_I$ = – $V_{th}$ = – AF $V_{s\ell}/V_I$ = – $V_{o\ell}/V_I$ = –

$E_e$ = 1822.0 ft z = 2 L = 200 ft $V_{sp}/V_I$ = 0.353
$V_{te}$ = 1000 AF Case 2 $S_o$ = 2 % $V_{sp}/V_I + V_{o\ell}/V_I$ = –
$V_{sp}$ = 930 AF $Q_h$ = 180 cfs (0.9 Qp) $V'_{sp}/V_I$ = $\boxed{0.375}$
$Q_{ph}$ = 200 cfs $Q_h/Q_I$ = 0.021 $V_{op}/V_I$ = 0.022

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $E_w$ ft | $V_{tw}$ AF | $V_{sw}$ AF | $V_{sw}/V_I$ | $V'_{sw}/V_I$ | $Q_O/Q_I$ | $Q_O$ cfs | $Q_e$ cfs | $H_p$ ft | $Q_e/b$ | b ft | $v_e$ fps |
| 1825.0 | 1190 | 1120 | 0.425 | 0.447 | 0.840 | 7140 | 6940 | 3.0 | 12.3 | 564 | 8.0 |
| 1825.5 | 1220 | 1150 | 0.436 | 0.458 | 0.805 | 6840 | 6640 | 3.5 | 16.2 | 410 | 8.8 |
| 1826.0 | 1250 | 1180 | 0.447 | 0.469 | 0.780 | 6630 | 6430 | 4.0 | 20.3 | 317 | 9.5 |
| 1826.5 | 1280 | 1210 | 0.459 | 0.481 | 0.760 | 6460 | 6260 | 4.5 | 25.0 | 250 | 10.1 |
| 1827.0 | 1310 | 1240 | 0.470 | 0.492 | 0.735 | 6250 | 6050 | 5.0 | 29.5 | 205 | 10.7 |
| 1827.5 | 1340 | 1270 | 0.482 | 0.504 | 0.705 | 5990 | 5790 | 5.5 | 35.0 | 165 | 11.4 |



The UD Method of Reservoir Flood Routing is accomplished by using charts composed of dimensionless ratios. The method solves the basic flood routing equation, inflow is equal to outflow plus the change in storage.

## Nomenclature

$R$ = Runoff

$Q_i$ = Inflow rate of hydrograph at any time

$Q_I$ = Peak inflow rate

$V_i$ = Inflow volume at any time

$V_I$ = Total inflow volume

$t_b$ = Time of base of inflow hydrograph

$q_p$ = Peak inflow rate of simple unit graph

$T_p$ = Time to peak of simple unit graph

$q_c$ = Inflow rate of composite unit graph at any time

$q_{cp}$ = Peak inflow rate of composite unit graph

$K$ = A coefficient equal to $V_{oe}/Q_o\ (t_w - t_e)$

## Assumptions

1. THE ORDINATES OF THE INFLOW HYDROGRAPH ARE PROPORTIONAL TO THE VOLUME OF RUNOFF FOR A GIVEN SHAPE OF HYDROGRAPH ($Q_i = Rq_c$). This is a universally accepted theory and needs no further explanation.

2. THE AREA UNDER THE ASCENDING LIMB OF THE OUTFLOW HYDROGRAPH ($V_{oe}$) DURING EMERGENCY SPILLWAY FLOW IS PROPORTIONAL TO THE PRODUCT OF THE PEAK OUTFLOW ($Q_o$) AND THE TIME INTERVAL FROM THE BEGINNING OF EMERGENCY SPILLWAY FLOW TO THE PEAK OUTFLOW ($t_w - t_e$) or $V_{oe} = KQ_o\ [t_w - t_e]$

   This approximation was used in the flood routing method given in National Technical Release No. 2. A value of 2/3 was recommended for K in this procedure. The coefficient K is a variable which depends on:

   1. The shape of the inflow hydrograph (Hydrograph Family and $T_o/T_p$)

   2. The volume of storage to the emergency spillway crest ($V_{sp}$)

   3. The peak outflow rate ($Q_o$)

   Some routings of actual hydrographs for Hydrograph Family 1 and 2, $T_o/T_p = 1.5$ were performed and the "K" coefficient determined.

This was the basis for determining all "K" coefficients used for the flood routing charts. Since all of the conditions affecting the value of K were not entirely evaluated, some approximation results, but the actual error involved in practical applications is small.

3. THE PRINCIPAL SPILLWAY RELEASE RATE IS A CONSTANT (OR CONSTANTS IF TWO OR MORE STAGES ARE INVOLVED) EQUAL TO THE AVERAGE RELEASE RATE (OR RATES). Any error in this assumption is negligible since the effect of the principal spillway outflow is generally minor when flood routing storms that produce flow through the emergency spillway.

## Derivation

The equations are derived by the following three steps:

1. Derivation of the Dimensionless Mass Inflow and Rate of Inflow Hydrographs.

2. Derivation of the Dimensionless Flood Routing Equation and Procedures Used in Its Solution.

3. Derivation of Expressions for the Independent Variables ($V'_{sp}/V_I$ and $V'_{sw}/V_I$).

### Step 1: Derivation of the Dimensionless Mass Inflow and Rate of Inflow Hydrographs

In order to derive the terms used in the solution of the dimensionless flood routing equation, a dimensionless mass inflow and rate of inflow hydrographs must be prepared. These can readily be computed from the composite unit graph values listed in NEH Section 4 for each hydrograph family and $T_o/T_p$ ratio. The final terms of the dimensionless hydrographs are $Q_i/Q_I$ and $V_i/V_I$ plotted against $t(Q_I/V_I)$.

Evaluation of $Q_i/Q_I$

The equation for evaluating $Q_i/Q_I$ is obtained as follows:

$$Q_i = R\, q_c \qquad \text{unit graph theory}$$

$$Q_i = R\, q_c\, (q_p/q_p)$$

therefore,

$$Q_i = R\, q_p\, (q_c/q_p)$$

and

$$Q_I = R\, q_p\, (q_{cp}/q_p)$$

Divide $Q_i$ by $Q_I$:

$$Q_i/Q_I = \frac{R\ q_p\ (q_c/q_p)}{R\ q_p\ (q_{cp}/q_p)}$$

$$Q_i/Q_I = \frac{q_c/q_p}{q_{cp}/q_p} \qquad \text{(Eq. 4-1)}$$

Since values for $q_c/q_p$ and $q_{cp}/q_p$ are given in NEH-4 for various hydrograph families and $T_o/T_p$ ratios, $Q_i/Q_I$ may be computed directly.

Evaluation of $V_i/V_I$

The equation for evaluating $V_i/V_I$ is obtained as follows:

$$V_I = {}_{o}^{t_b}\ Q_i\ dt$$

Area under rate of inflow hydrograph is equal to total volume of inflow

Replace integral with series term, using equal increments of time units:

$$V_I = [\frac{Q_o + Q_1}{2} + \frac{Q_1 + Q_2}{2} + \ldots + \frac{Q_{n-1} + Q_n}{2}]\ \Delta t$$

where the $n^{th}$ term occurs at $t_b$ and $Q_o$ and $Q_n$ equal the rates of inflow at the beginning and end of inflow, respectively.

$$Q_o = Q_n = 0.$$

therefore,

$$V_I = [Q_1 + Q_2 + \ldots + Q_{n-1}]\ \Delta t$$

$$\Sigma_o^{t_b}\ Q_i = [Q_1 + Q_2 + \ldots + Q_{n-1}]$$

therefore,

$$V_I = (\Sigma_o^{t_b}\ Q_i)\ \Delta t \qquad \text{(Eq. 4-2)}$$

and

$$V_i = \ Q_i\ dt$$

Area under rate of inflow hydrograph at any time is equal to the volume of inflow at that time

Replace integral with series term using equal increments of time units

$$V_i = \left[\frac{Q_o + Q_1}{2} + \frac{Q_1 + Q_2}{2} + \ldots + \frac{Q_{n-1} + Q_n}{2}\right] \Delta t$$

Since $Q_o = 0$

$$V_i = [Q_1 + Q_2 + \ldots + Q_{n-1} + Q_n/2] \Delta t$$

Note that $Q_n$ is equal to zero only at $t_b$

$$V_i = [Q_1 + Q_2 + \ldots + Q_{n-1} + Q_n/2 + Q_n/2 - Q_n/2] \Delta t$$

$$= [Q_1 + Q_2 + \ldots + Q_n - Q_n/2] \Delta t$$

let

$$\Sigma_o^n Q_i = [Q_1 + Q_2 + \ldots + Q_n]$$

then

$$V_i = [(\Sigma_o^n Q_i) - Q_n/2] \Delta t \qquad \text{(Eq. 4-3)}$$

Divide $V_i$ by $V_I$ (Equation 4-2)

$$V_i/V_I = \frac{[(\Sigma_o^n Q_i) - Q_n/2] \Delta t}{(\Sigma_o^{t_b} Q_i) \Delta t}$$

$$= \frac{(\Sigma_o^n Q_i) - Q_n/2}{\Sigma_o^{t_b} Q_i}$$

Divide numerator and denominator by $Q_I$

$$V_i/V_I = \frac{(\Sigma_o^n Q_i/Q_I) - \frac{Q_n/Q_I}{2}}{\Sigma_o^{t_b} Q_i/Q_I} \qquad \text{(Eq. 4-4)}$$

Since $V_i/V_I$ is expressed entirely in terms of $Q_i/Q_I$ and since $Q_i/Q_I$ is expressed entirely in terms of $q_c/q_p$, then $V_i/V_I$ may be computed directly from the values given in NEH-4 for each hydrograph family and $T_o/T_p$ ratio.

Evaluation of $t(Q_I/V_I)$

The equation for evaluating $t(Q_I/V_I)$ is obtained as follows:

$$V_I = (\Sigma_o^{t_b} Q_i)\,\Delta t \qquad \text{(Eq. 4-2)}$$

Invert and multiply both sides by $(Q_I\ T_p)$

$$\frac{Q_I\ T_p}{V_I} = \frac{Q_I\ T_p}{(\Sigma_o^{t_b} Q_i)\,\Delta t}$$

$$= \frac{1}{(\Sigma_o^{t_b} Q_i/Q_I)\,\Delta t/T_p} \qquad \text{(Eq. 4-5)}$$

Since the term $(\Sigma_o^{t_b} Q_i/Q_I)$ can be computed directly from the values of $q_c/q_p$ for equal $\Delta t/T_p$ increments from NEH-4 for the various hydrograph families and $T_o/T_p$ ratios, $\frac{Q_I\ T_p}{V_I}$ may be computed from equation 4-5.

The values of $t/T_p$ given in NEH-4 may then be multiplied by $\frac{Q_I\ T_p}{V_I}$ resulting in

$$(t/T_p)\,\frac{Q_I\ T_p}{V_I} = t(Q_I/V_I) \qquad \text{(Eq. 4-6)}$$

With equations 4-1, 4-4, and 4-6 and the $q_c/q_p$ and $t/T_p$ values listed in NEH-4 for each hydrograph family and $T_o/T_p$ ratio, values of $Q_i/Q_I$ and $V_i/V_I$ may be computed and plotted against $t(Q_I/V_I)$. (See Fig. 4-1)

<u>Step 2: Derivation of the Dimensionless Flood Routing Equation and Procedures Used in its Solution</u>

$$V_i = V_s + V_o$$ General Conservation of Mass Equation.

$$V_{iw} = V_{sw} + (V_{op} + V_{oe})$$ Substitute specific values at $t_w$ for the general conservation of mass equation.

Since $V'_{sw} = V_{sw} + V_{op}$ by definition

$$V_{iw} = V'_{sw} + V_{oe}$$

Assume $V_{oe} = K\ Q_o\ (t_w - t_e)$, then  Assumption 2

$$V_{iw} = V'_{sw} + K\ Q_o\ (t_w - t_e)$$

Divide both sides by $V_I$ and multiply $Q_o$ by $Q_I/Q_I$, obtain

$$V_{iw}/V_I = V'_{sw}/V_I + K[Q_o/Q_I]\,[Q_I/V_I]\,(t_w - t_e)$$

or

$$V'_{sw}/V_I = V_{iw}/V_I - K\,Q_o/Q_I\,[t_w\,(Q_I/V_I) - t_e\,(Q_I/V_I)] \qquad \text{(Eq. 4-7)}$$

This is the dimensionless flood routing equation.

Values for substitution in the dimensionless flood routing equation can be obtained from the dimensionless hydrographs (see Fig. 4-1) as follows:

1. Establish $V'_{sp}/V_I$, this fixes the time, $t_e\ (Q_I/V_I)$.
2. Establish $Q_o/Q_I$, this fixes the time, $t_w\ (Q_I/V_I)$ and also the inflow volume $V_{iw}/V_I$.

All of the terms in equation 4-7 may be read from the dimensionless hydrographs after assigning specific values for $V'_{sp}/V_I$ and $Q_o/Q_I$. Consequently, $V'_{sw}/V_I$ may be computed from equation 4-7. Therefore, charts may be prepared for the various hydrograph families and $T_o/T_p$ ratios which are a solution of equation 4-7 with $V'_{sp}/V_I$ and $V'_{sw}/V_I$ as the independent variables and $Q_o/Q_I$ as the dependent variable.

Step 3: Derivation of Expressions for the Independent Variables ($V'_{sp}/V_I$ and $V'_{sw}/V_I$) and the Procedure for Their Solution

Evaluation of $V'_{sp}/V_I$

Express $V'_{sp}/V_I$ in terms of $V_i/V_I$:

Since,

$$V_i = V_s + V_o$$

then

$$V_{ie}/V_I = V_{sp}/V_I + V_{op}/V_I \text{ at } t_e$$

also by definition,

$$V'_{sp}/V_I = V_{sp}/V_I + V_{op}/V_I \text{ at } t_e \qquad \text{(Eq. 4-8)}$$

therefore,

$$V_{ie}/V_I = V'_{sp}/V_I$$

This means that $V'_{sp}/V_I$ is equal to the $V_i/V_I$ value on the dimensionless mass inflow curve at time $t_e$.

Express $V'_{sp}/V_I$ in terms of the principal spillway release rate $(Q_h/Q_I)$ and the available flood storage $(V_{sp}/V_I)$:

let, $V'_s = V_{sp} + V_{op}$

and, $V_{op} = Q_h\ t$      Assumption 3

then, $V'_s = V_{sp} + Q_h\ t$

and, $V'_s/V_I = V_{sp}/V_I + Q_h/Q_I\ [t\ (Q_I/V_I)]$

also, $V'_{sp}/V_I = V_{sp}/V_I + V_{op}/V_I$ at $t_e$      by definition

at time $t_e$, the term $V_{op}/V_I$ is equal to $Q_h/Q_I\ [t_e\ (Q_I/V_I)]$

therefore,

$$V'_{sp}/V_I = V_{sp}/V_I + Q_h/Q_I\ [t_e\ (Q_I/V_I)]$$

Solve for $V'_{sp}/V_I$ in terms of $Q_h/Q_I$, $V_{sp}/V_I$, and $V_i/V_I$:

The solution for $V'_{sp}/V_I$ can be best illustrated graphically (see Fig. 4-2). $V_i/V_I$ is the dimensionless mass inflow curve and may be plotted versus $t\ (Q_I/V_I)$. The equation for $V'_s/V_I$ is a straight line whose intercept on the $V/V_I$ axis is $V_{sp}/V_I$ and its slope is equal to $Q_h/Q_I$. Since $V'_s/V_I$ is equal to $V_i/V_I$ at time $t_e$, the intersection of the straight line with the dimensionless mass inflow hydrograph is the solution for $V'_{sp}/V_I$.

Evaluation of $V'_{sw}/V_I$

Solve for $V'_{sw}/V_I$ in terms of $V_{sw}/V_I$ and $V_{sp}/V_I$:

$V'_{sw} = V_{sw} + V_{op}$      by definition

$V'_{sw}/V_I = V_{sw}/V_I + V_{op}/V_I$

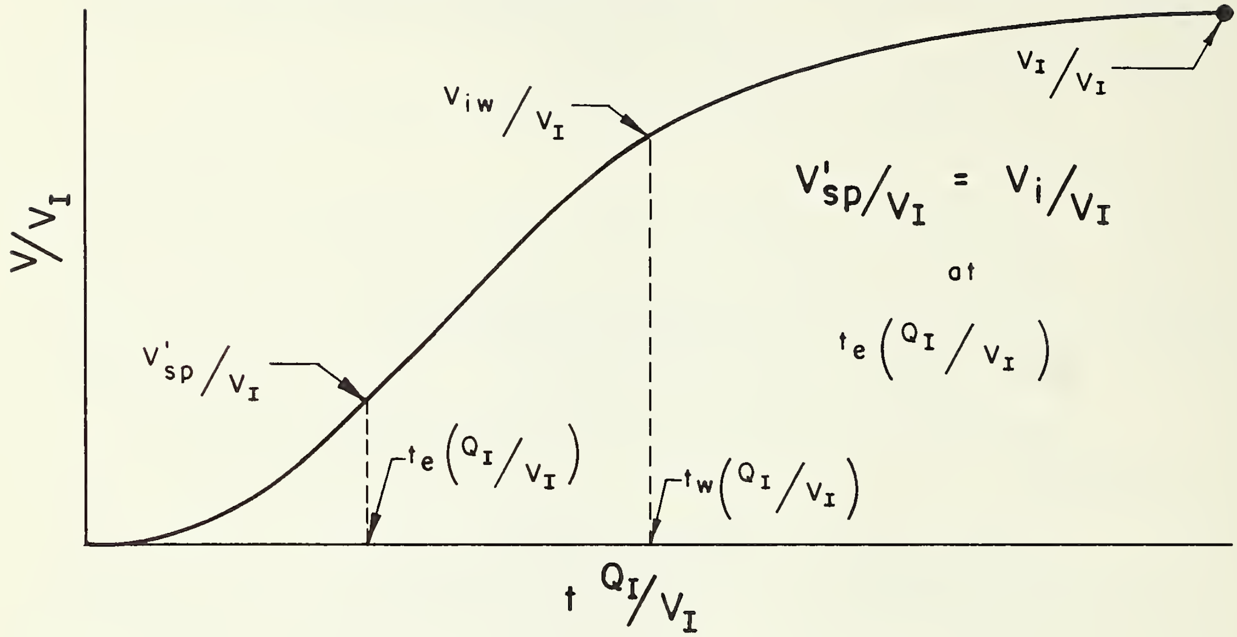
but, $V_{op}/V_I = V'_{sp}/V_I - V_{sp}/V_I$      (Eq. 4-8, rearranged)

therefore, $V'_{sw}/V_I = V_{sw}/V_I + (V'_{sp}/V_I - V_{sp}/V_I)$      (Eq. 4-9)

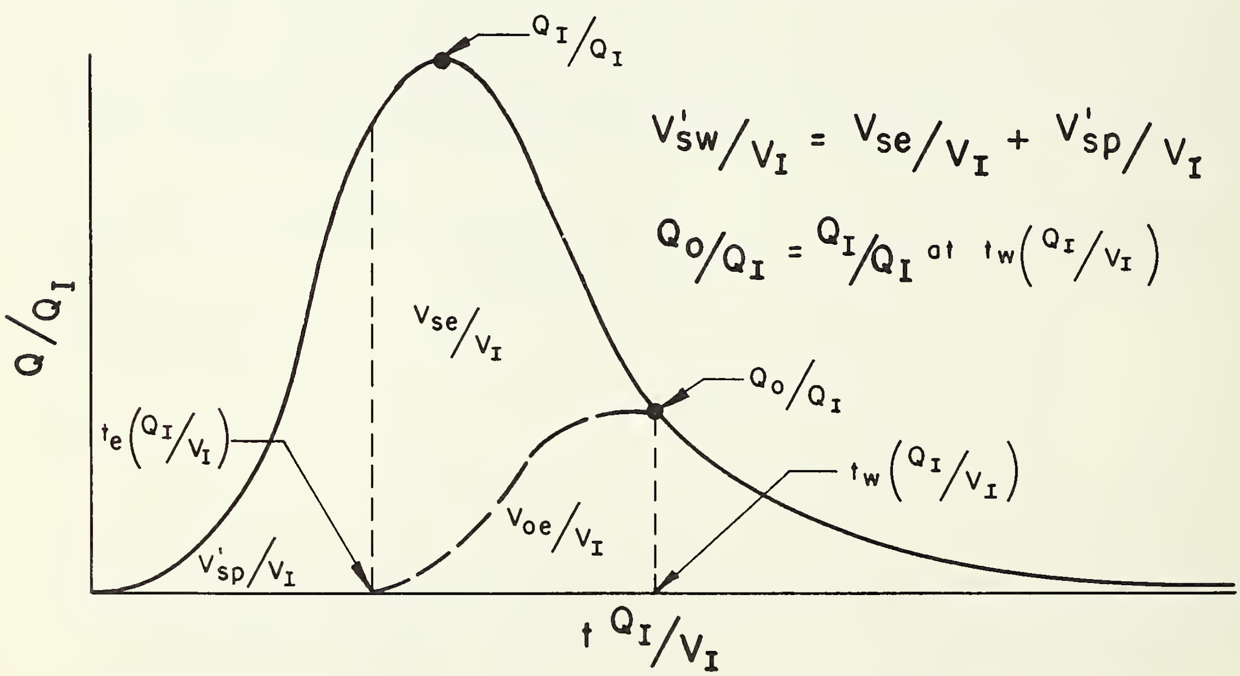
Charts have been prepared using the dimensionless mass inflow curve discussed in step 1. Following the prescribed graphical procedure permits the solution for $V'_{sp}/V_I$ for the selected hydrograph family and $T_o/T_p$ ratio. Equation 4-9 may then be solved for the value of $V'_{sw}/V_I$ which is used in performing the flood routing by the use of the dimensionless flood routing charts.

FIGURE 4-1

## DIMENSIONLESS MASS INFLOW HYDROGRAPH




## DIMENSIONLESS RATE OF FLOW HYDROGRAPH

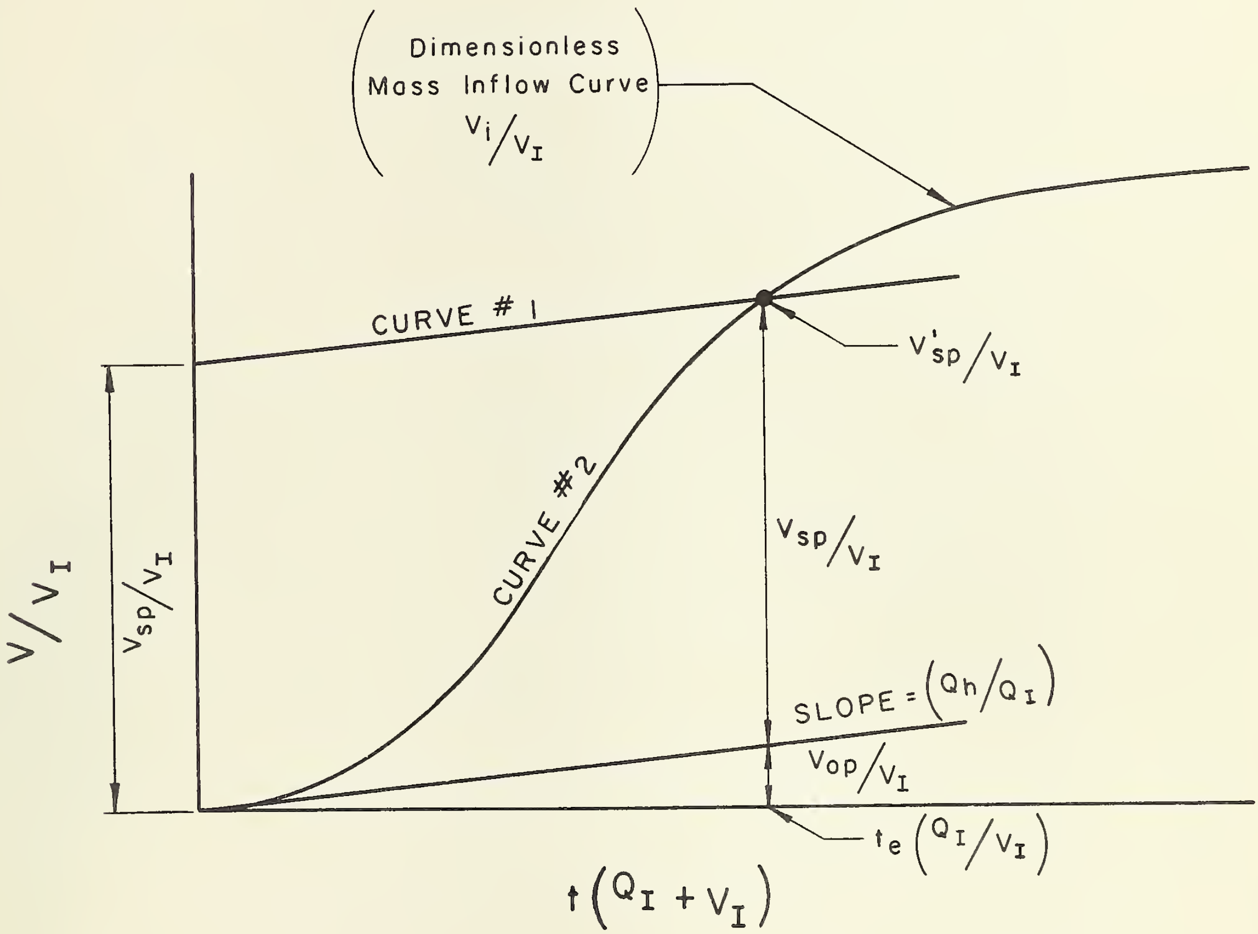



$$V'_{sw}/V_I = V_{iw}/V_I - K\left[Q_o/Q_I\right]\left[t_w(Q_I/V_I) - t_e(Q_I/V_I)\right]$$

FIGURE 4-2

Equation for CURVE # 1: $V'/V_I = V_{sp}/V_I + Q_h/Q_I \left(t\, Q_I / V_I\right)$

Equation for CURVE # 2: $$V_i / V_I = \frac{\left(\sum_0^n Q_i / Q_I\right) + \frac{Q_n / Q_I}{2}}{\sum_0^{tb} Q_i / Q_I}$$

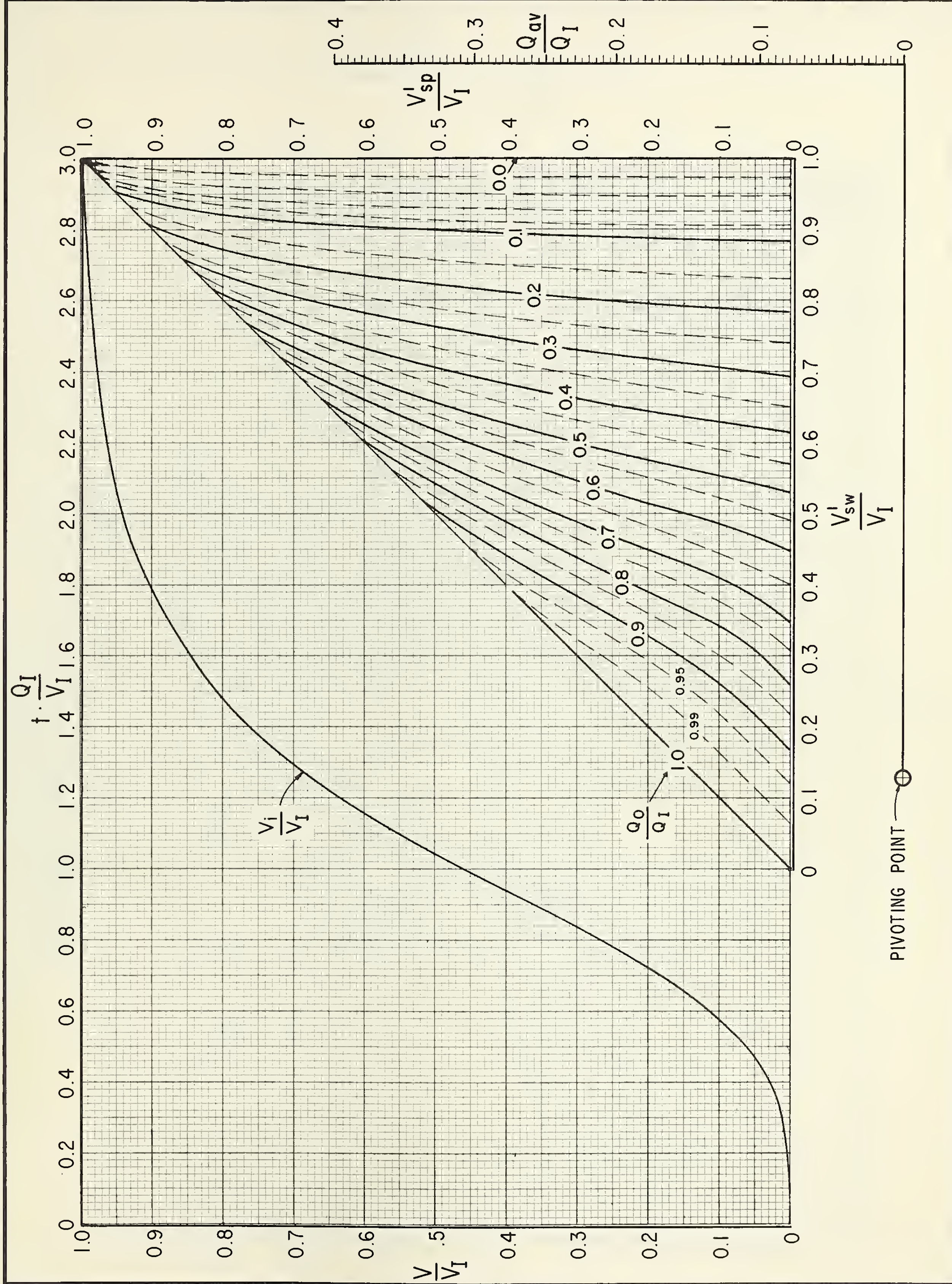



$V'_{sp} = V_{sp} + V_{op}$ By Definition

$V'_{sw} = V_{sw} + V_{op}$ By Definition

$V_{op} = (Q_h)(t)$ Assumption # 3

# UD METHOD: RESERVOIR FLOOD ROUTING CHARTS

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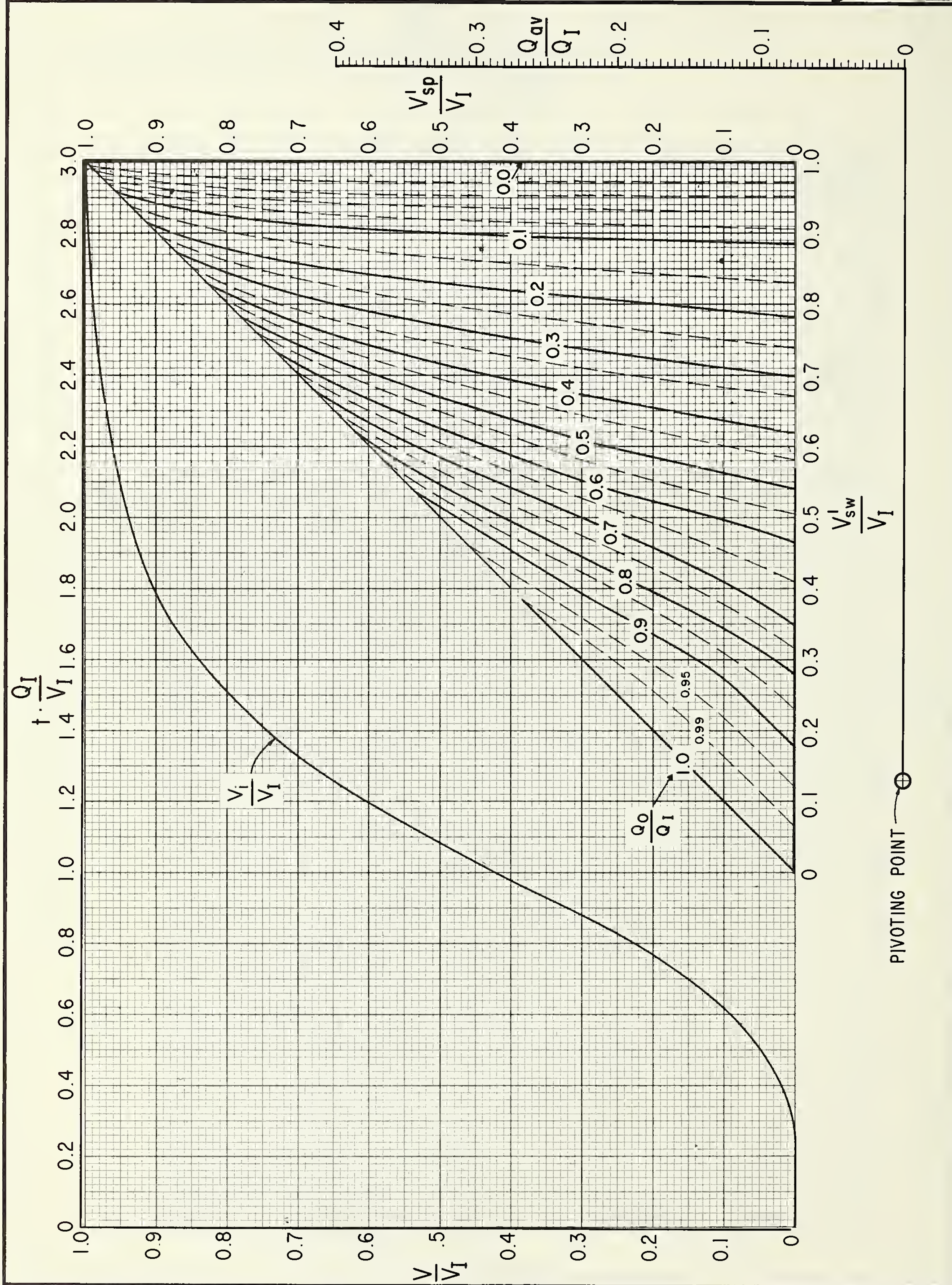


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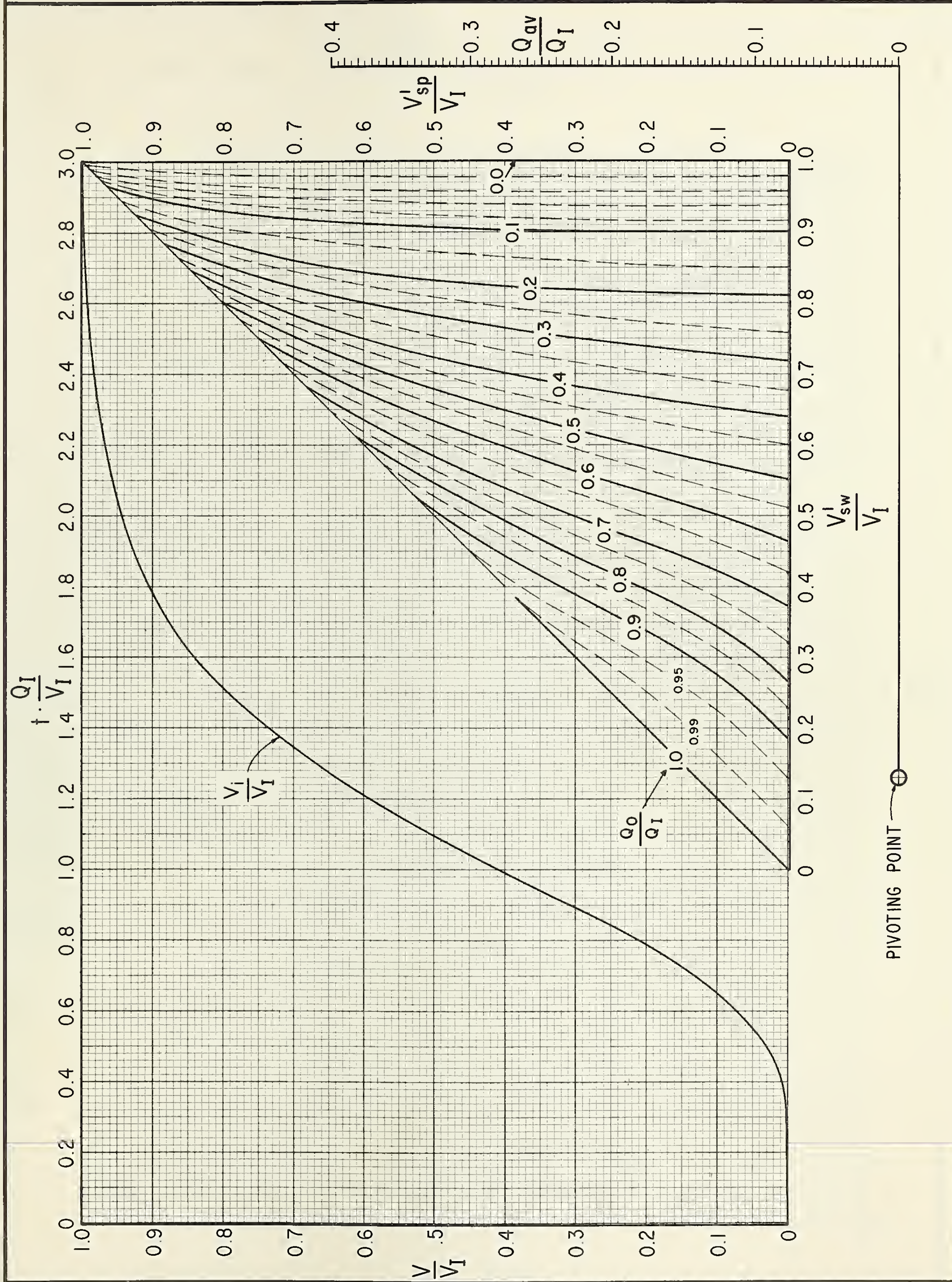
# UD METHOD: RESERVOIR FLOOD ROUTING CHARTS

1/2

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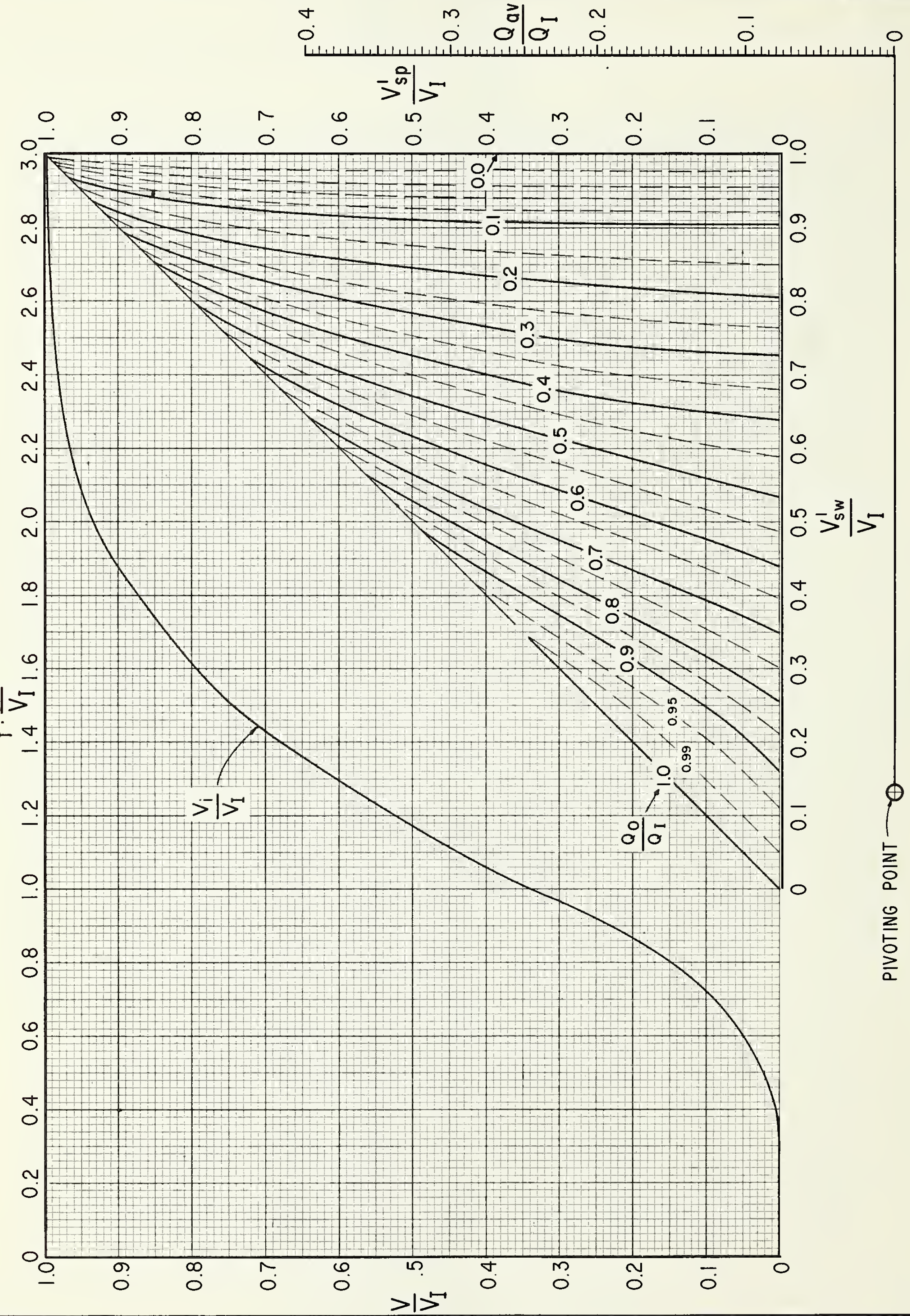
# UD METHOD: RESERVOIR FLOOD ROUTING CHARTS



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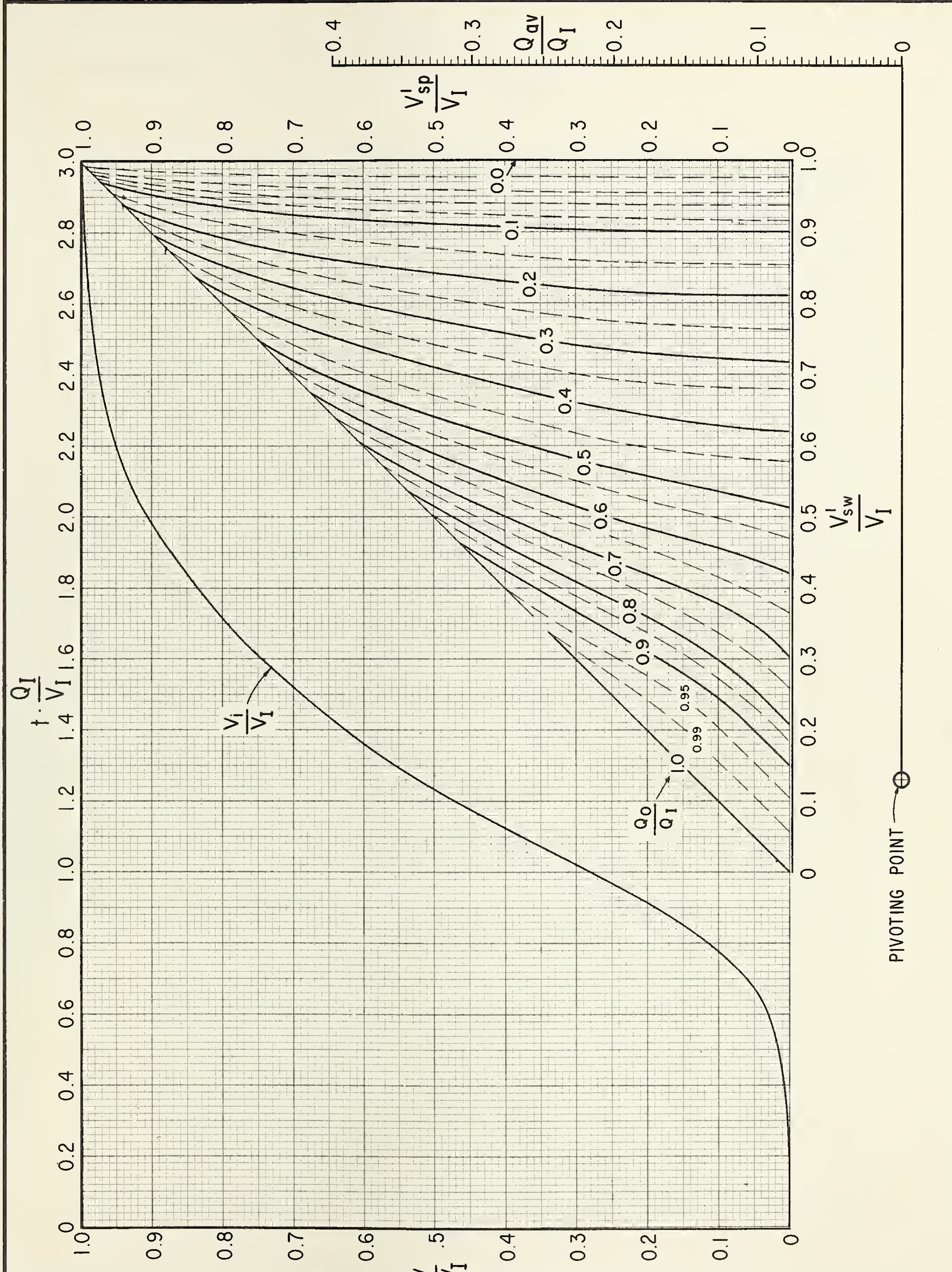


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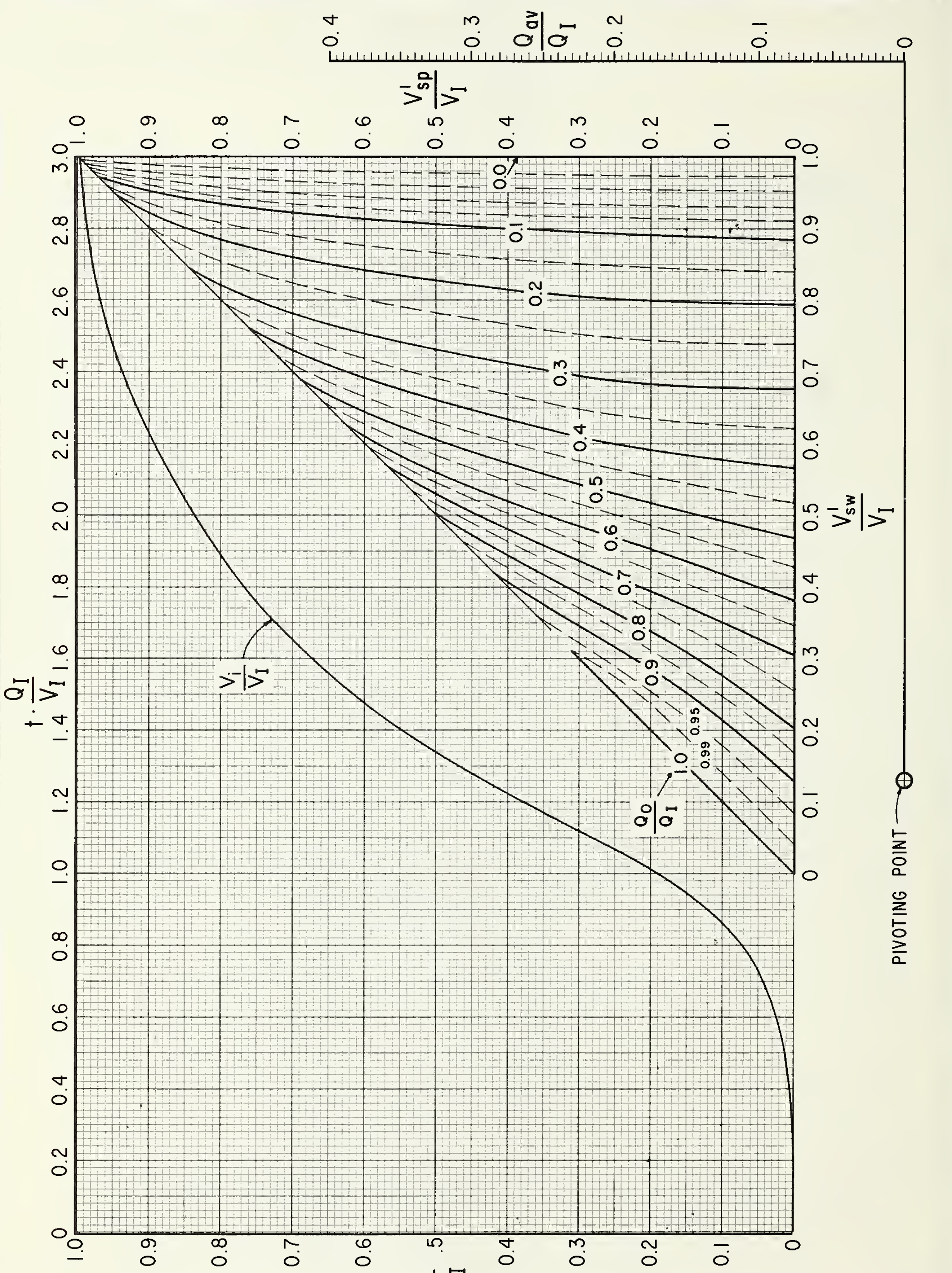


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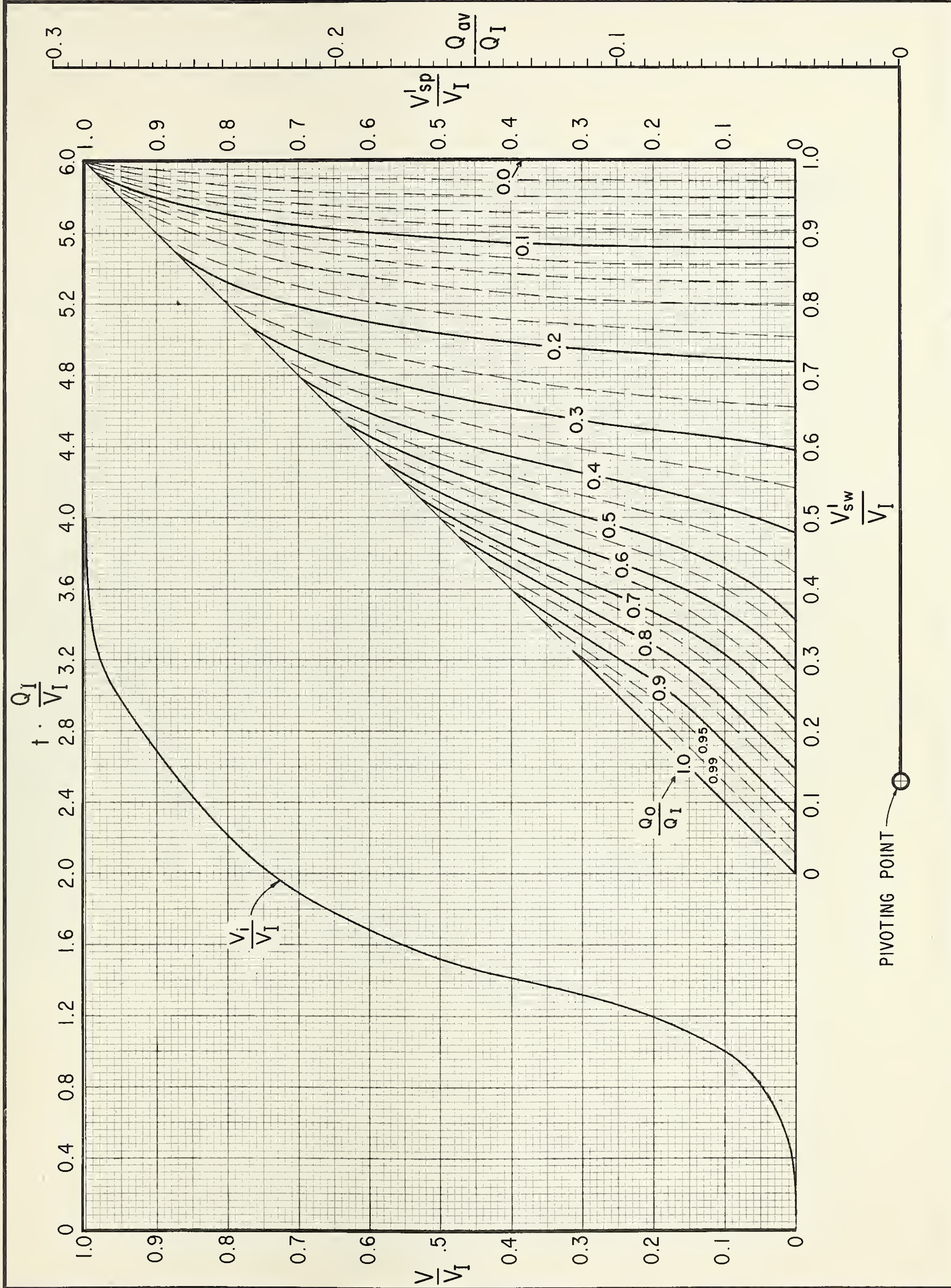


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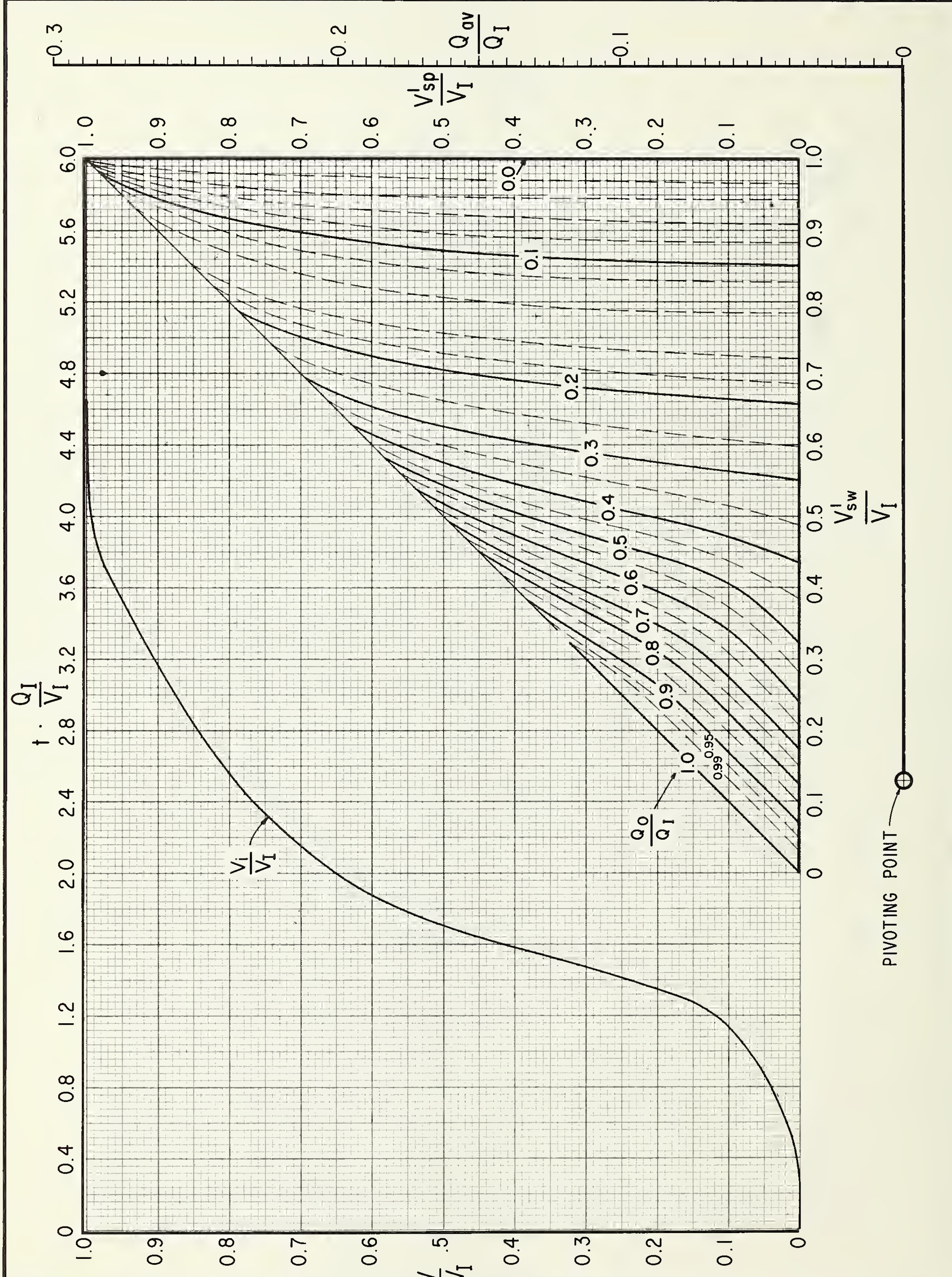


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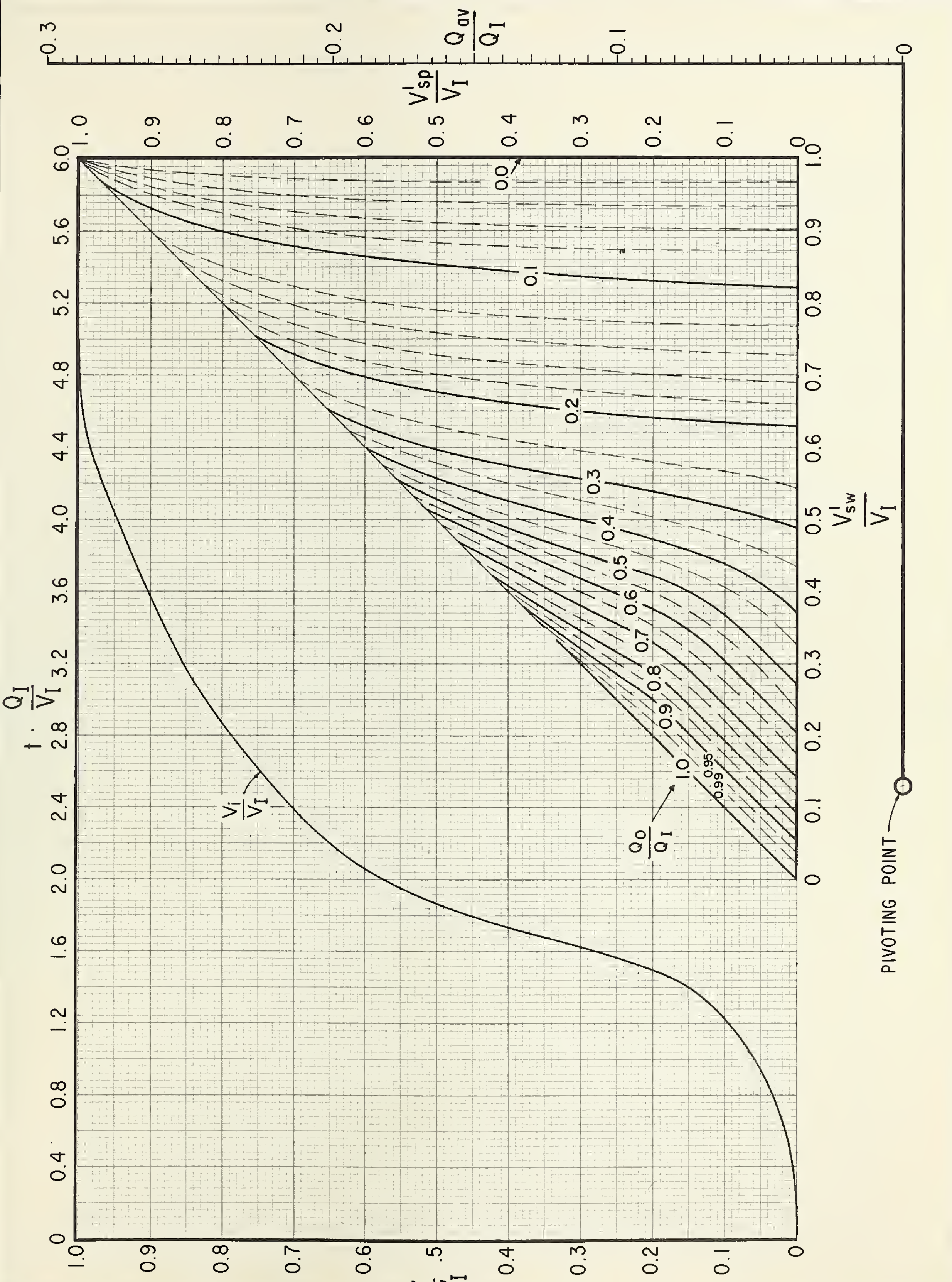


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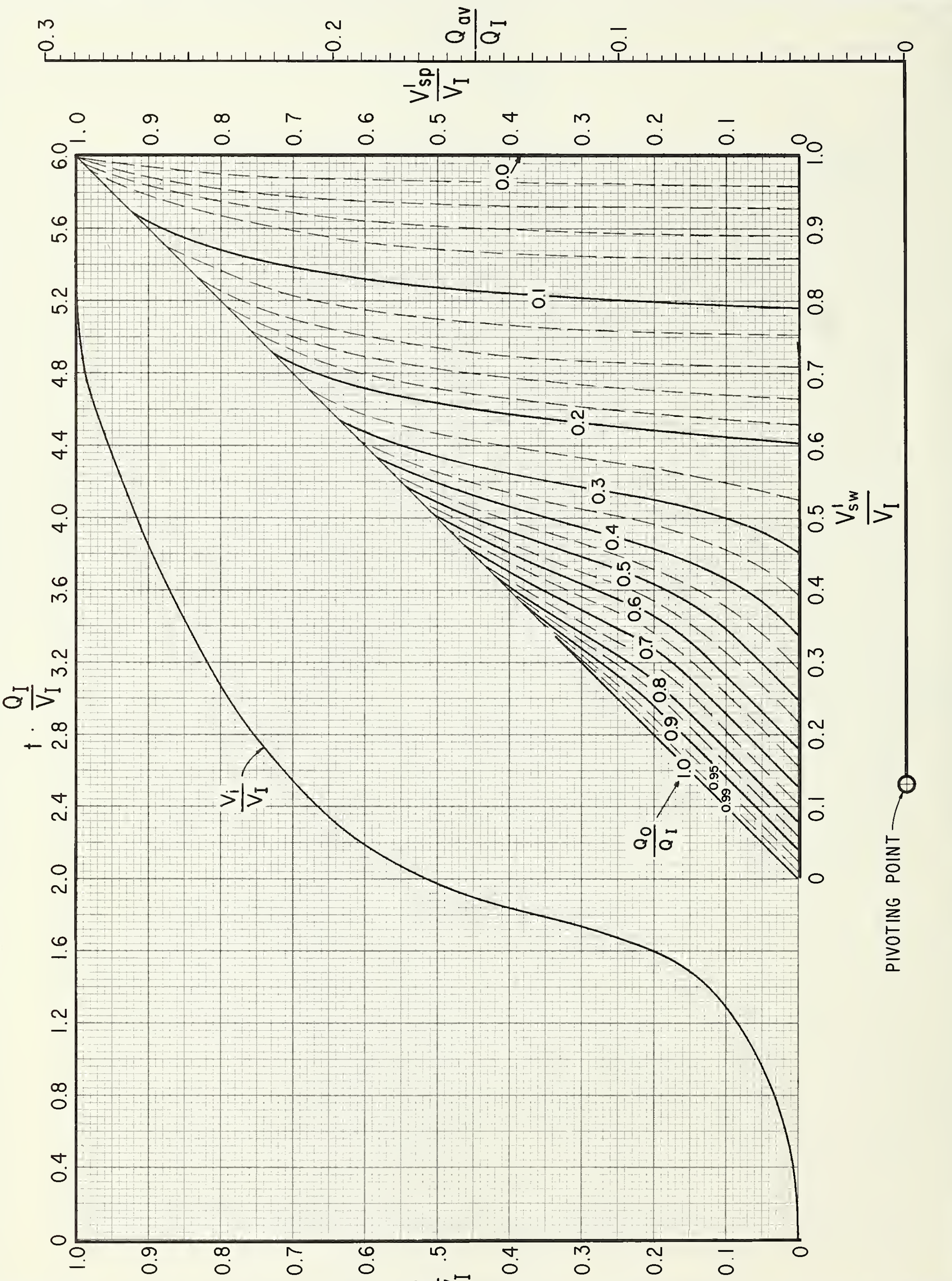


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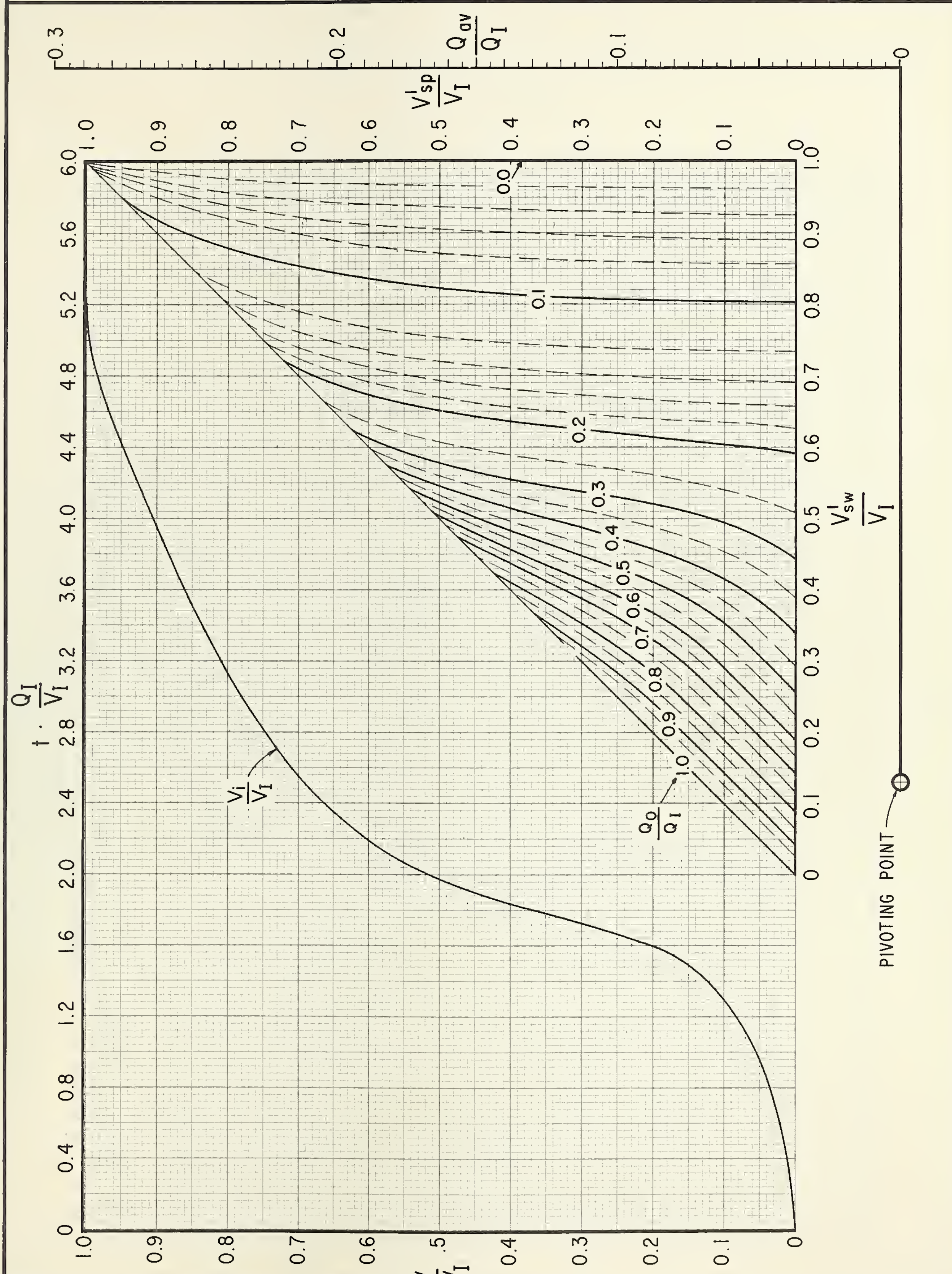


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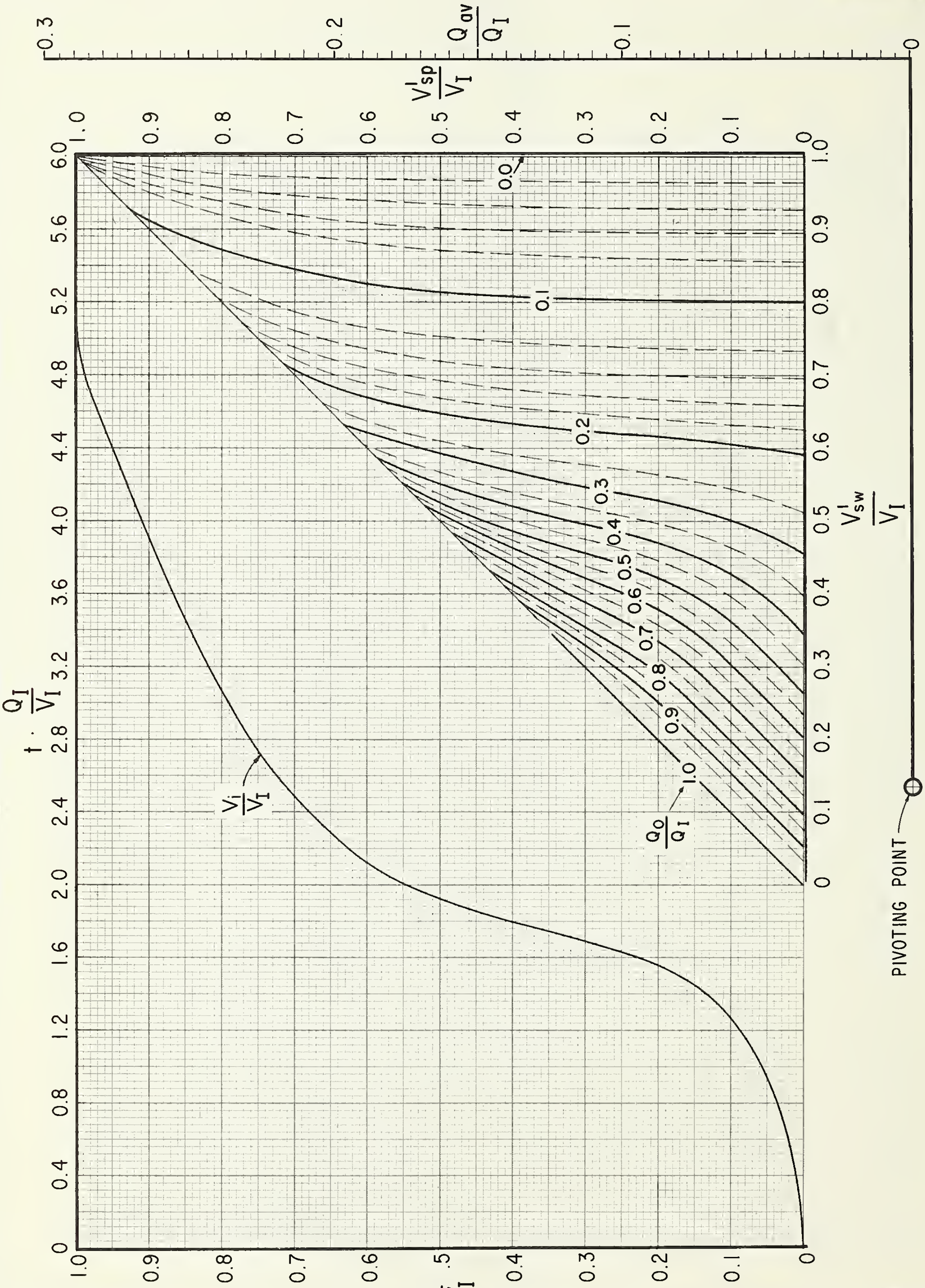
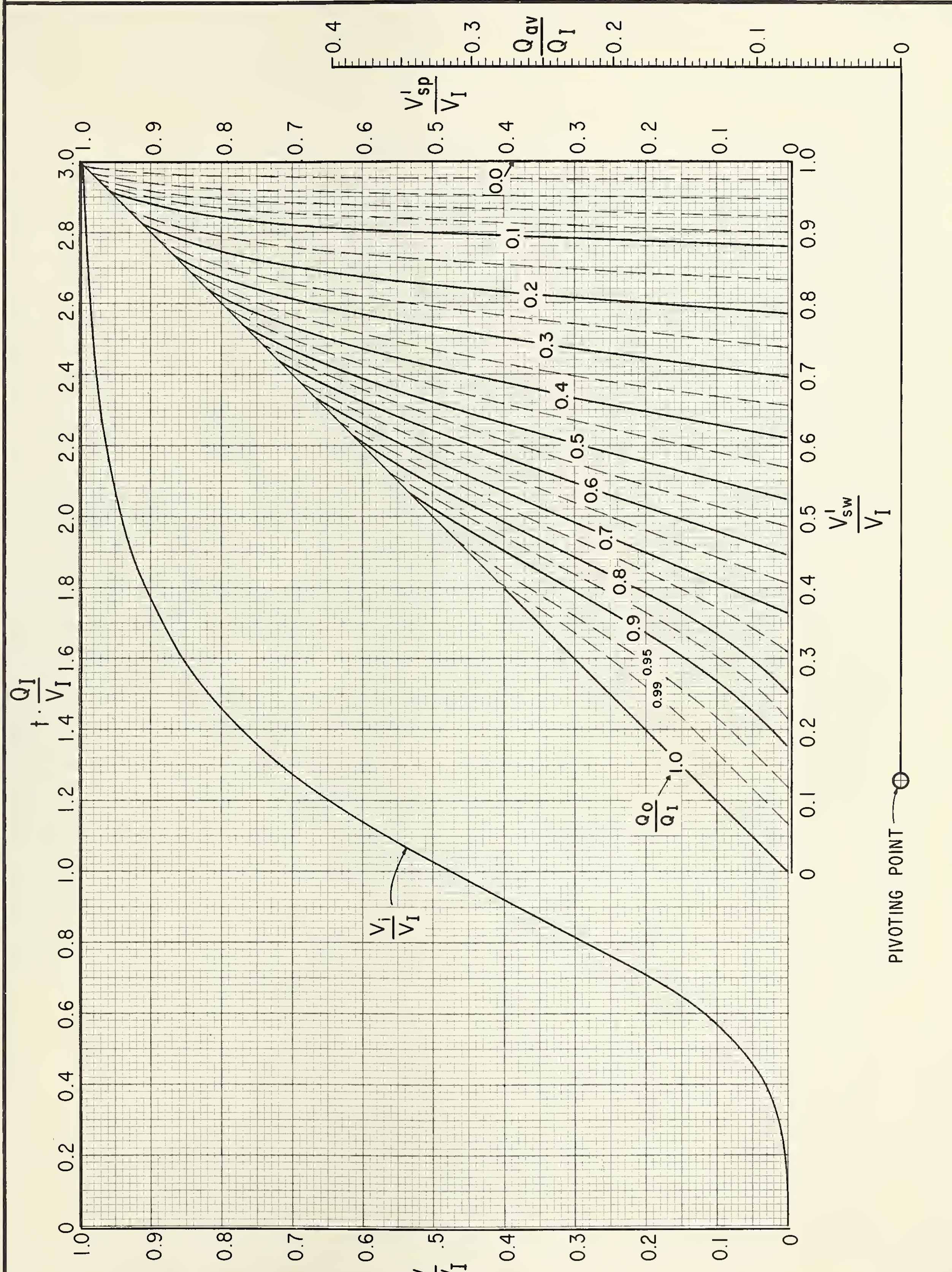


$\frac{Q_{av}}{Q_I}$
0.3
0.2
0.1
0
$\frac{V'_{sp}}{V_I}$
$t \cdot \frac{Q_I}{V_I}$
$\frac{V_i}{V_I}$
$\frac{Q_o}{Q_I}$
$\frac{V'_{sw}}{V_I}$
$\frac{V}{V_I}$
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
PIVOTING POINT

# UD METHOD: RESERVOIR FLOOD ROUTING CHARTS

2/1

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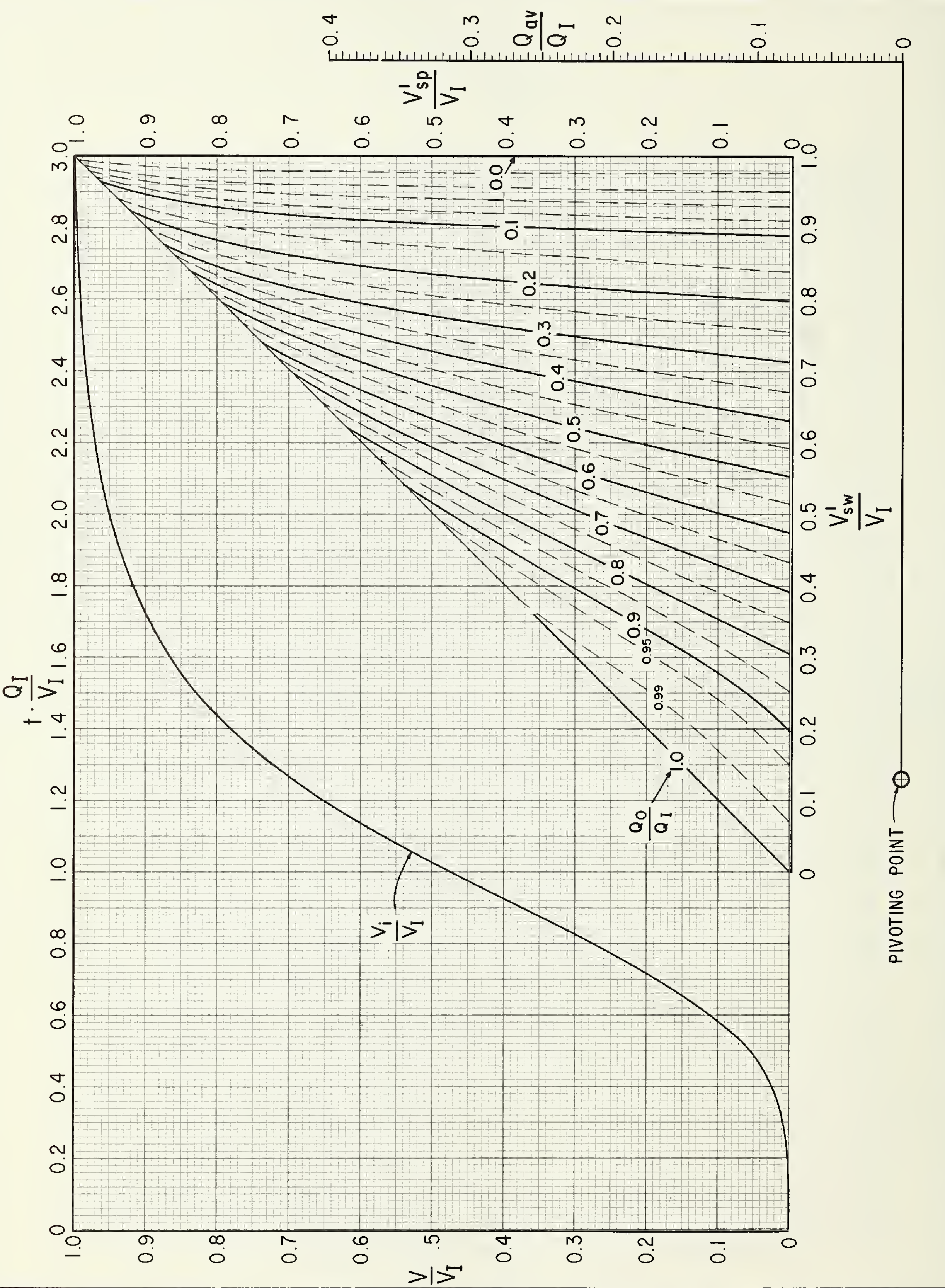
# UD METHOD: RESERVOIR FLOOD ROUTING CHARTS

2 / 1.5

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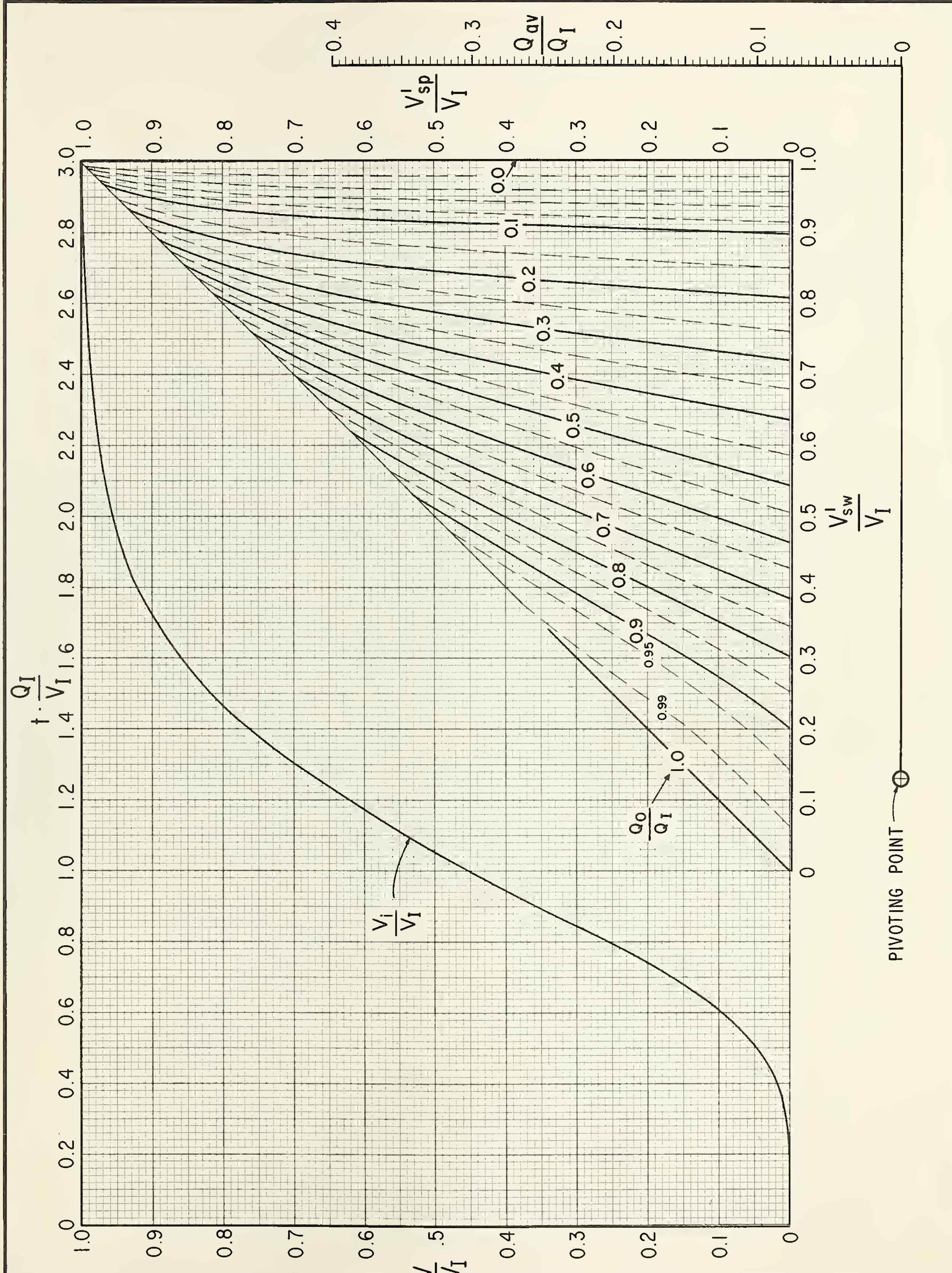


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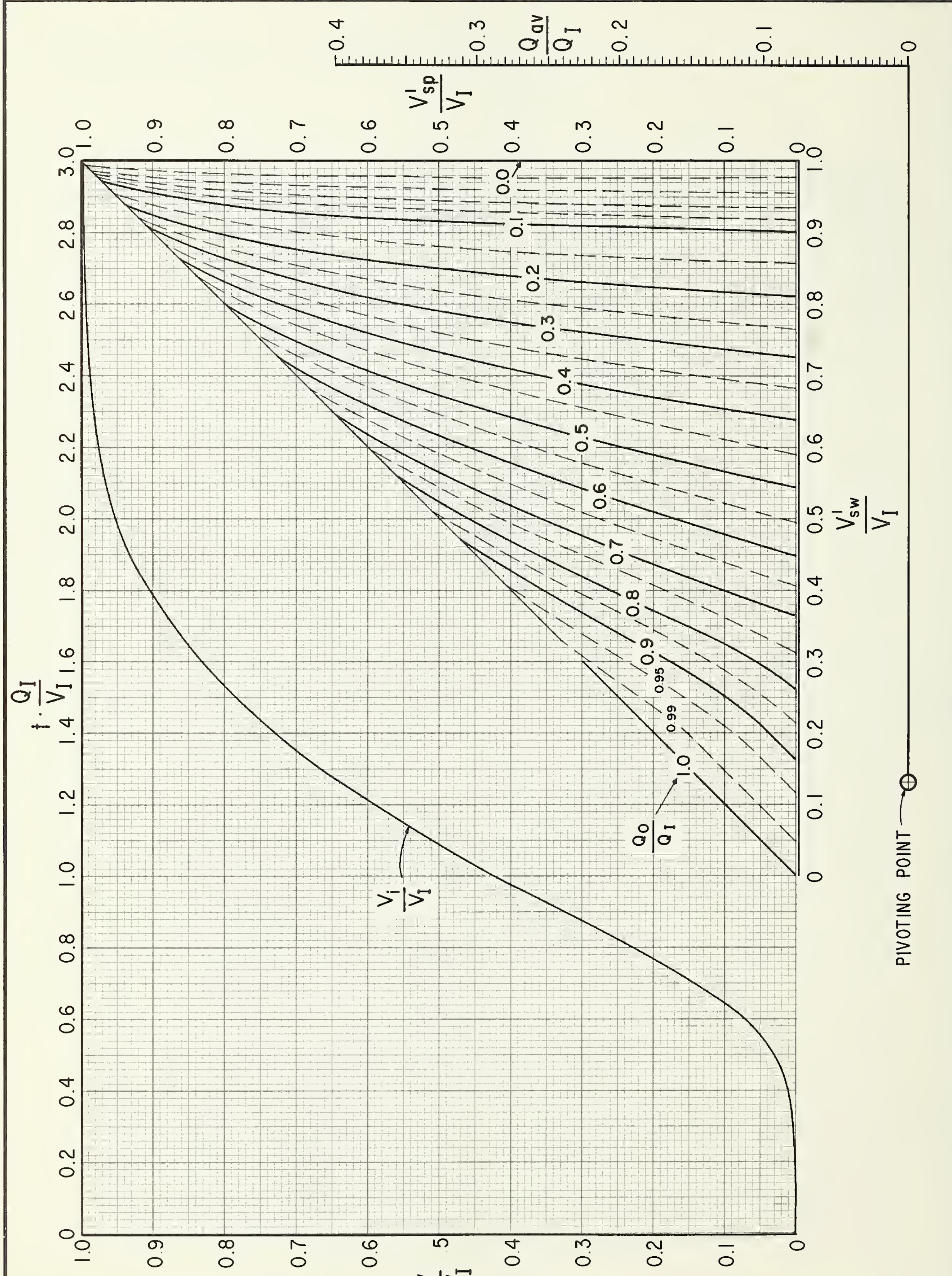


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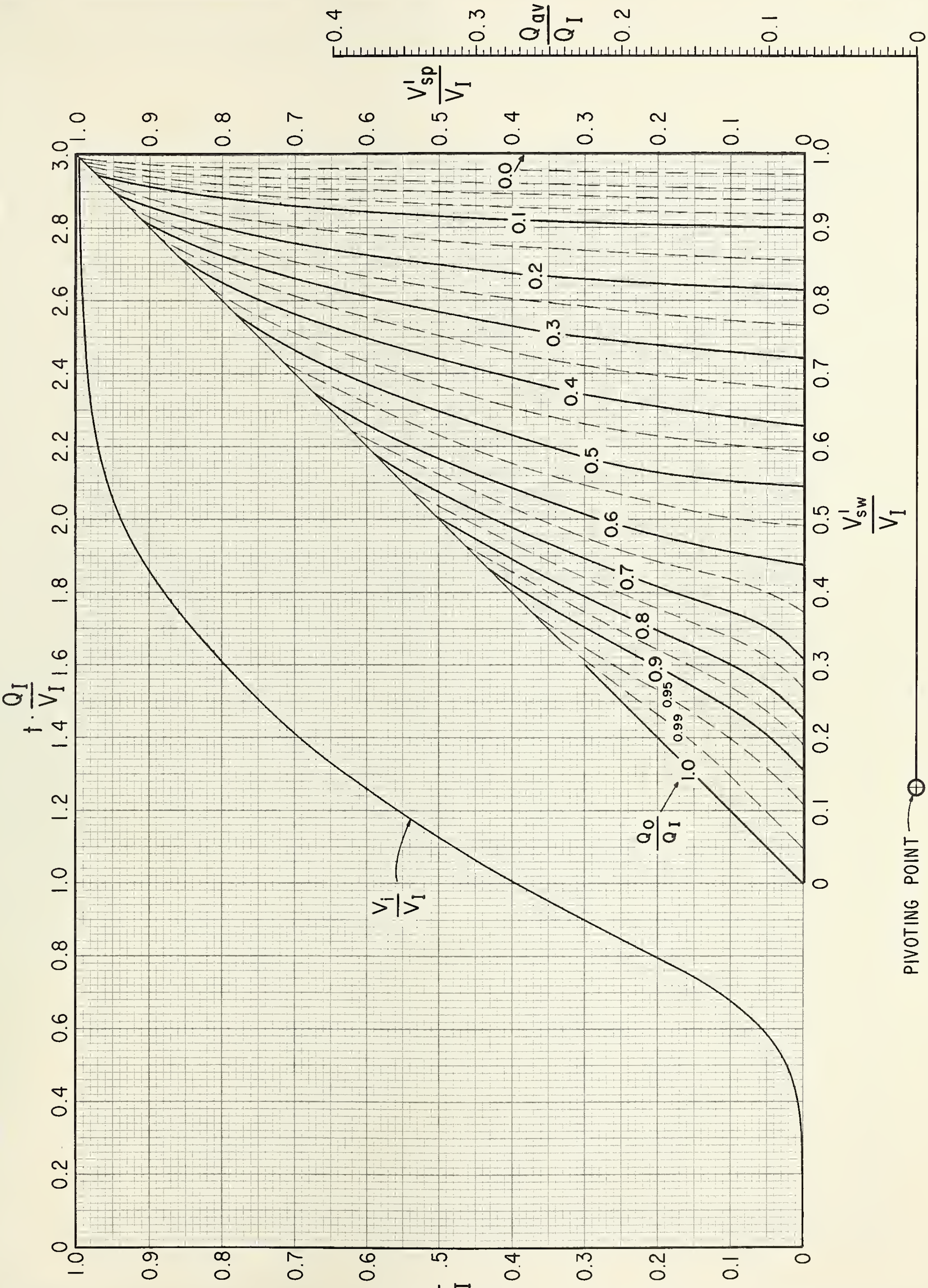
2/4

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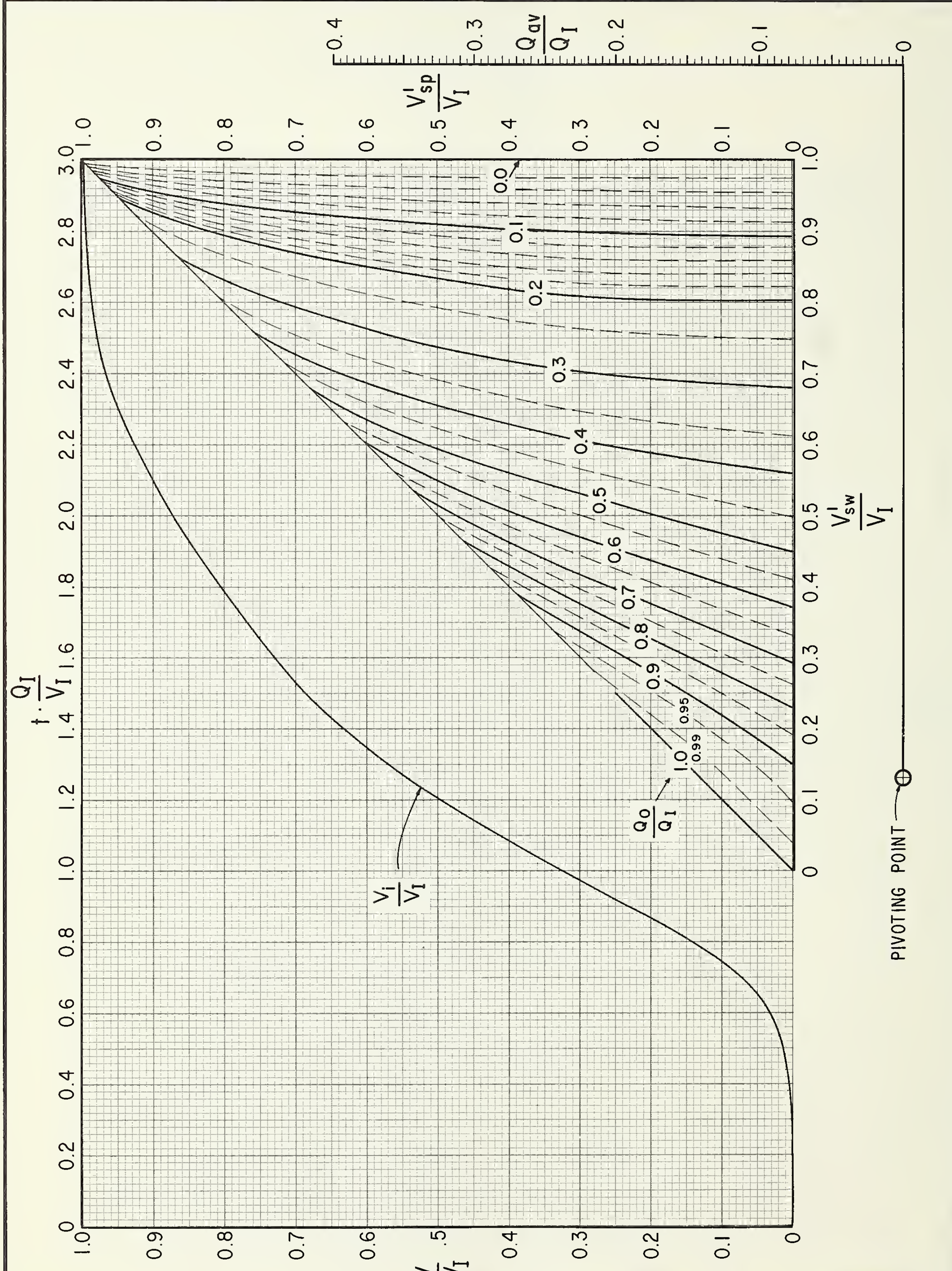


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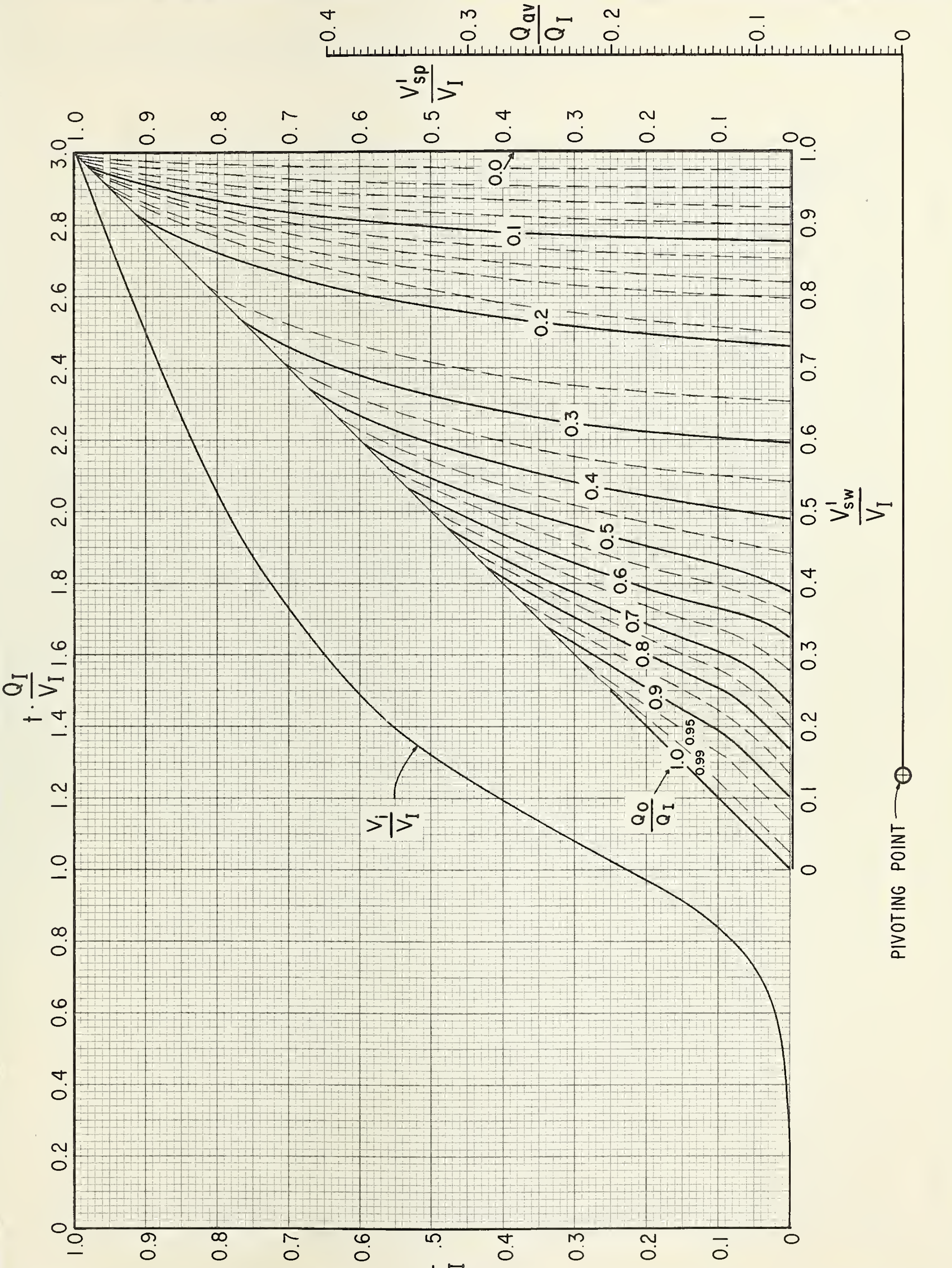


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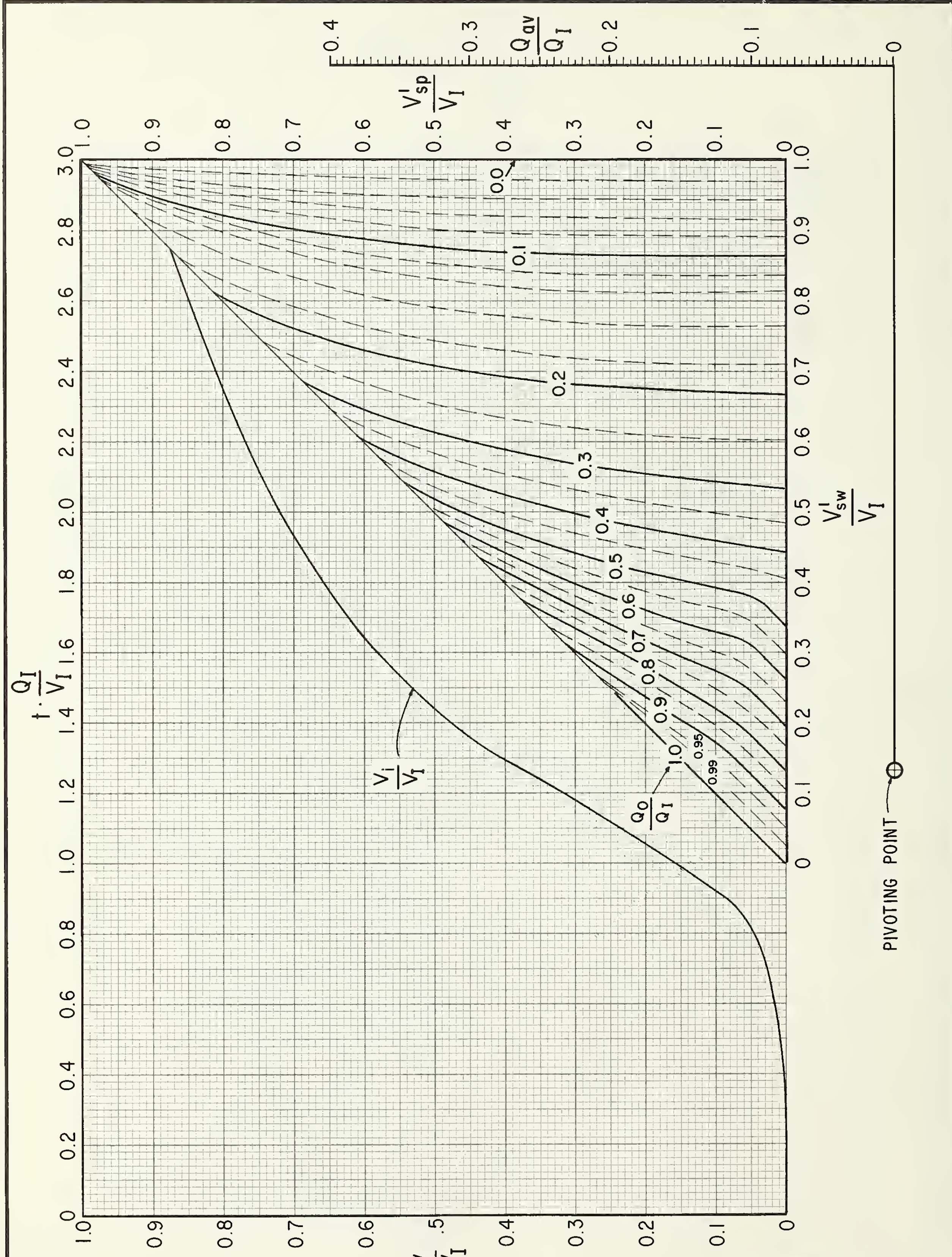


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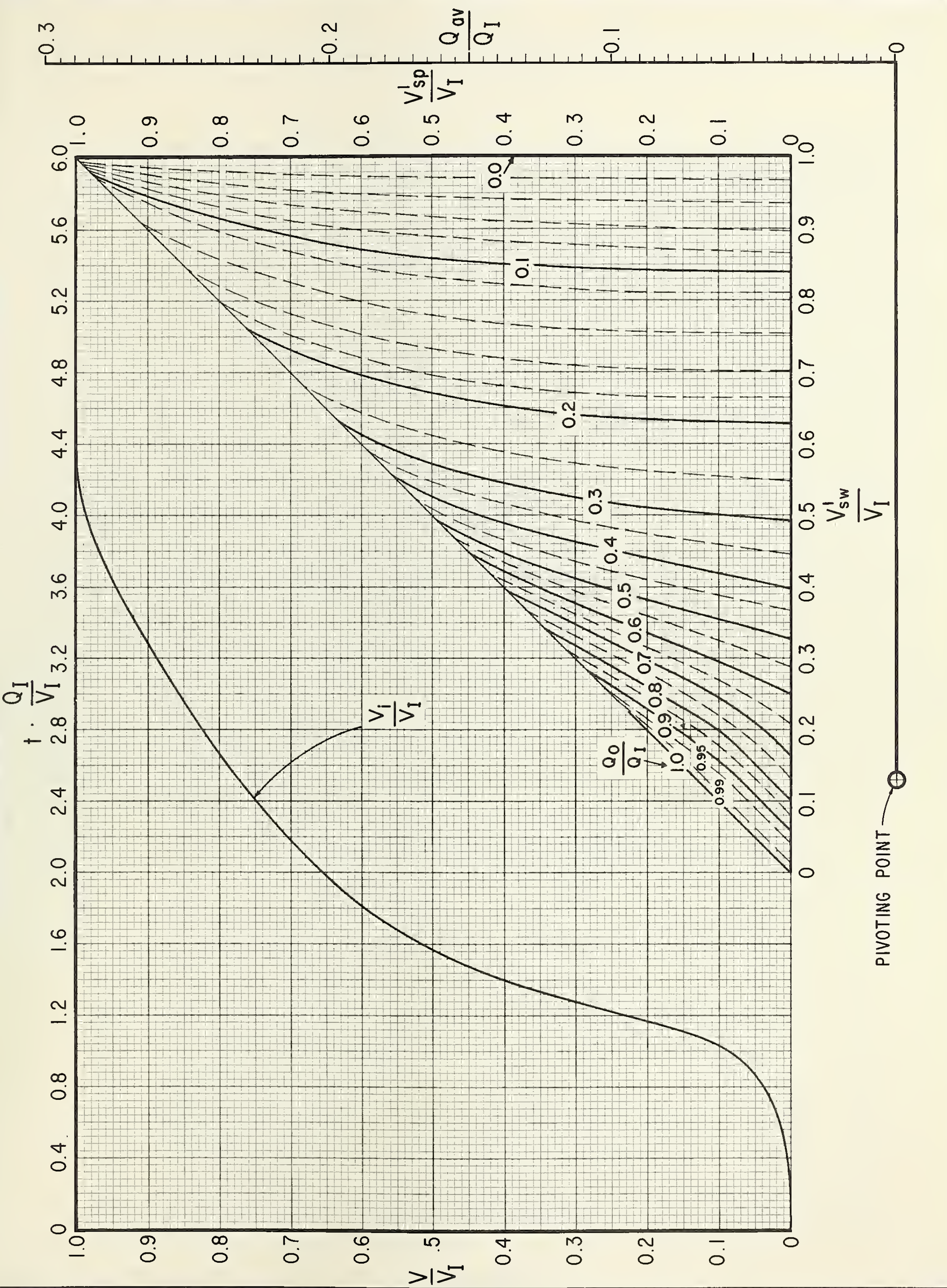


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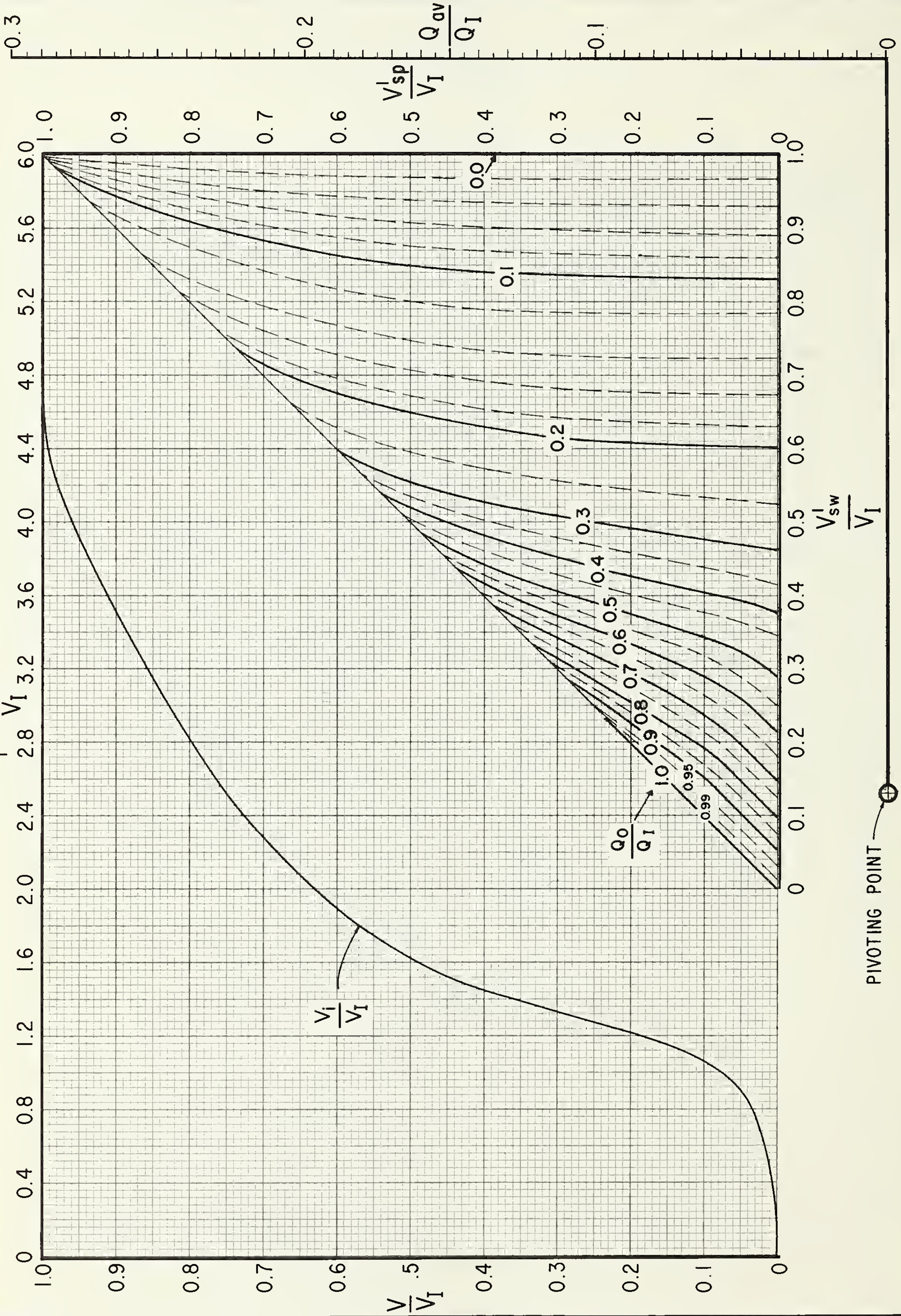


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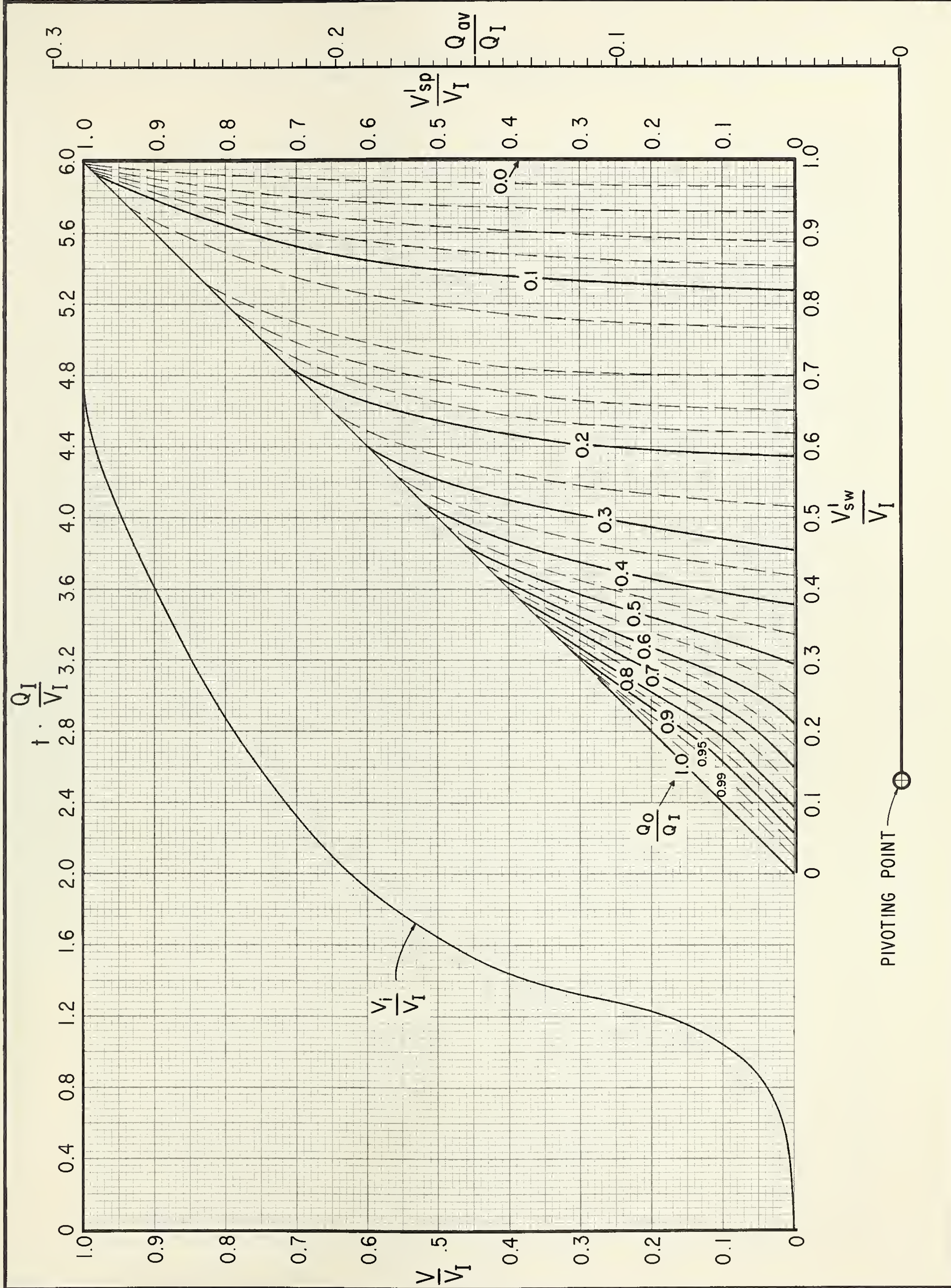


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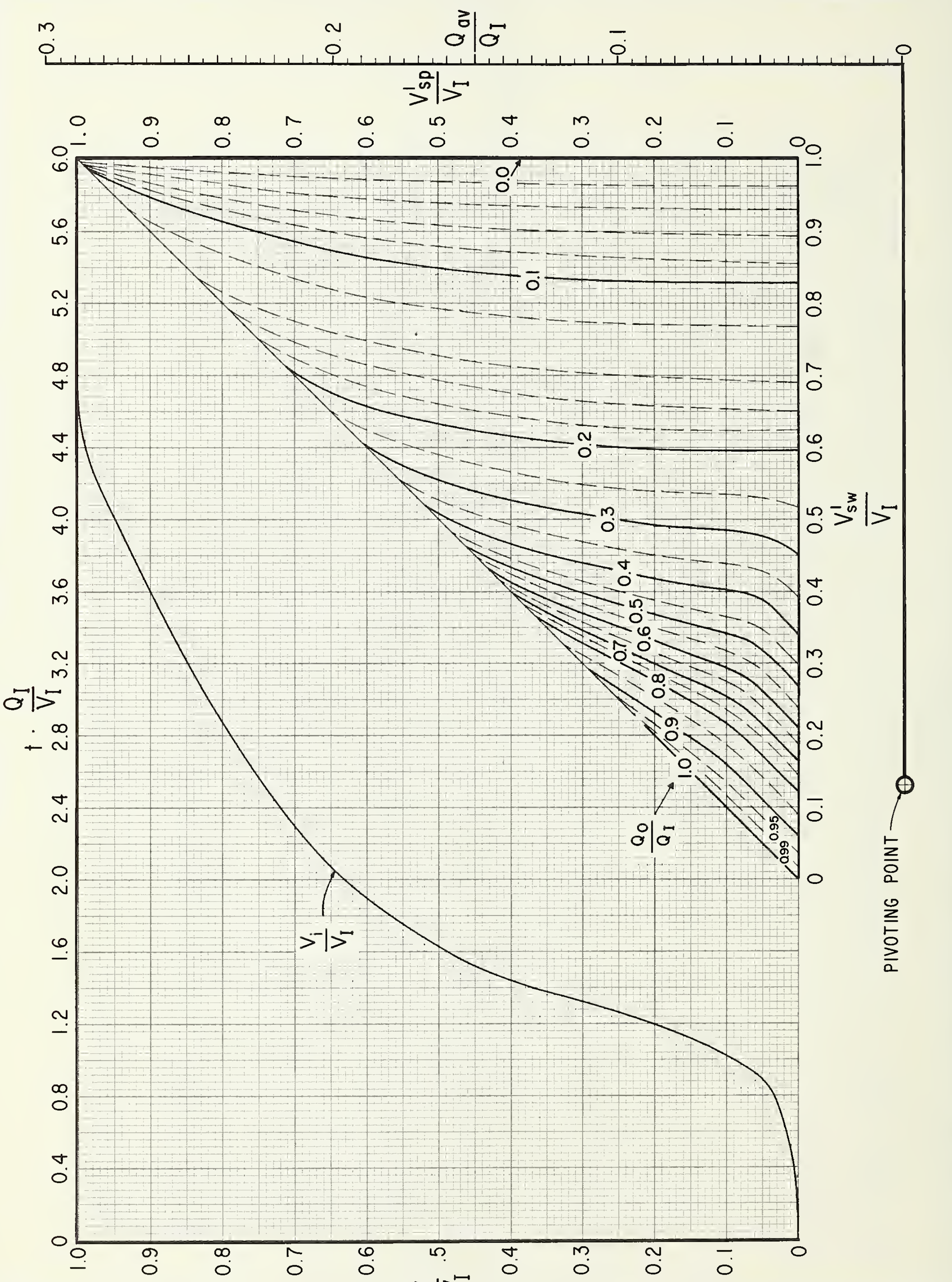


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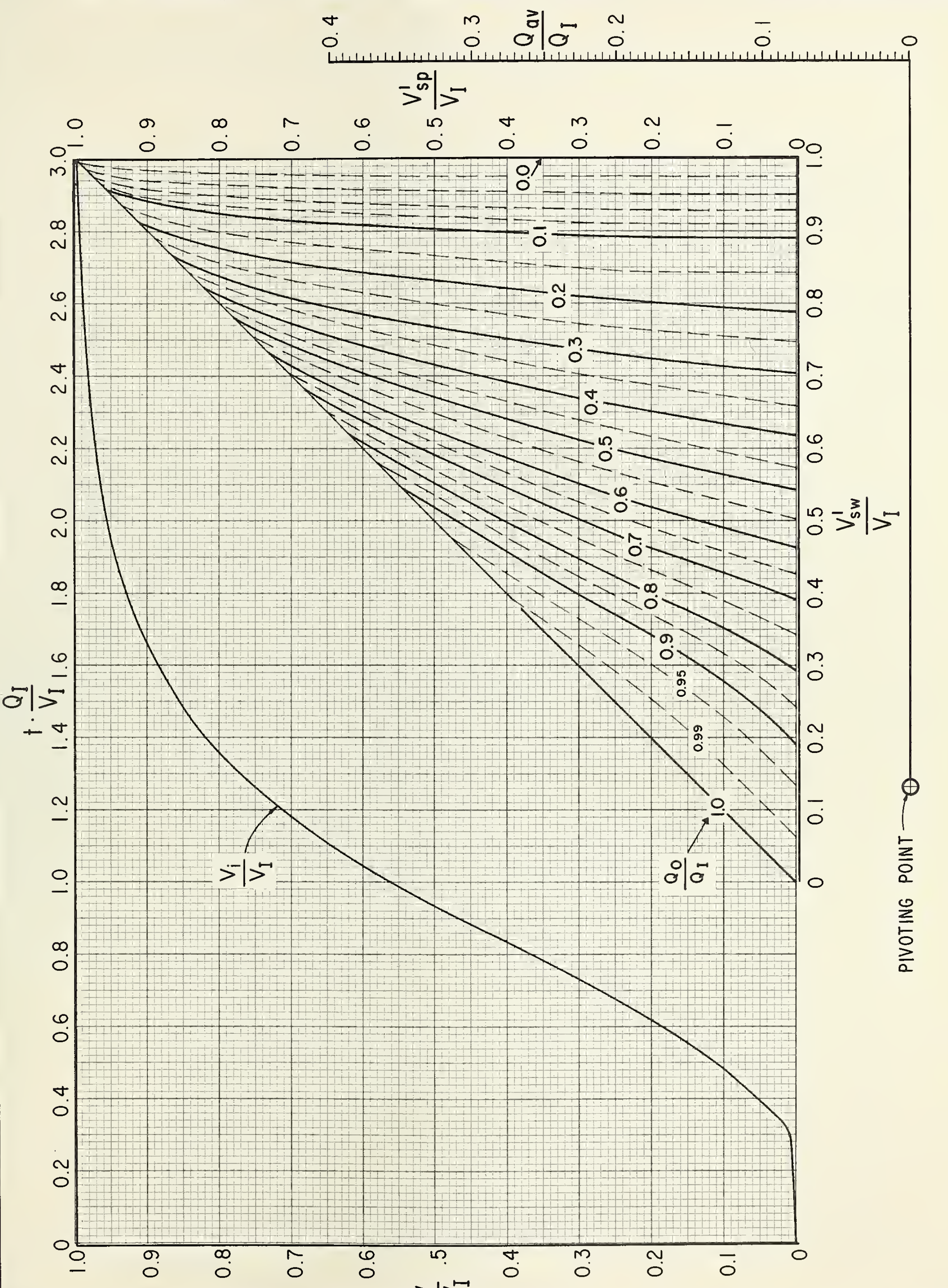


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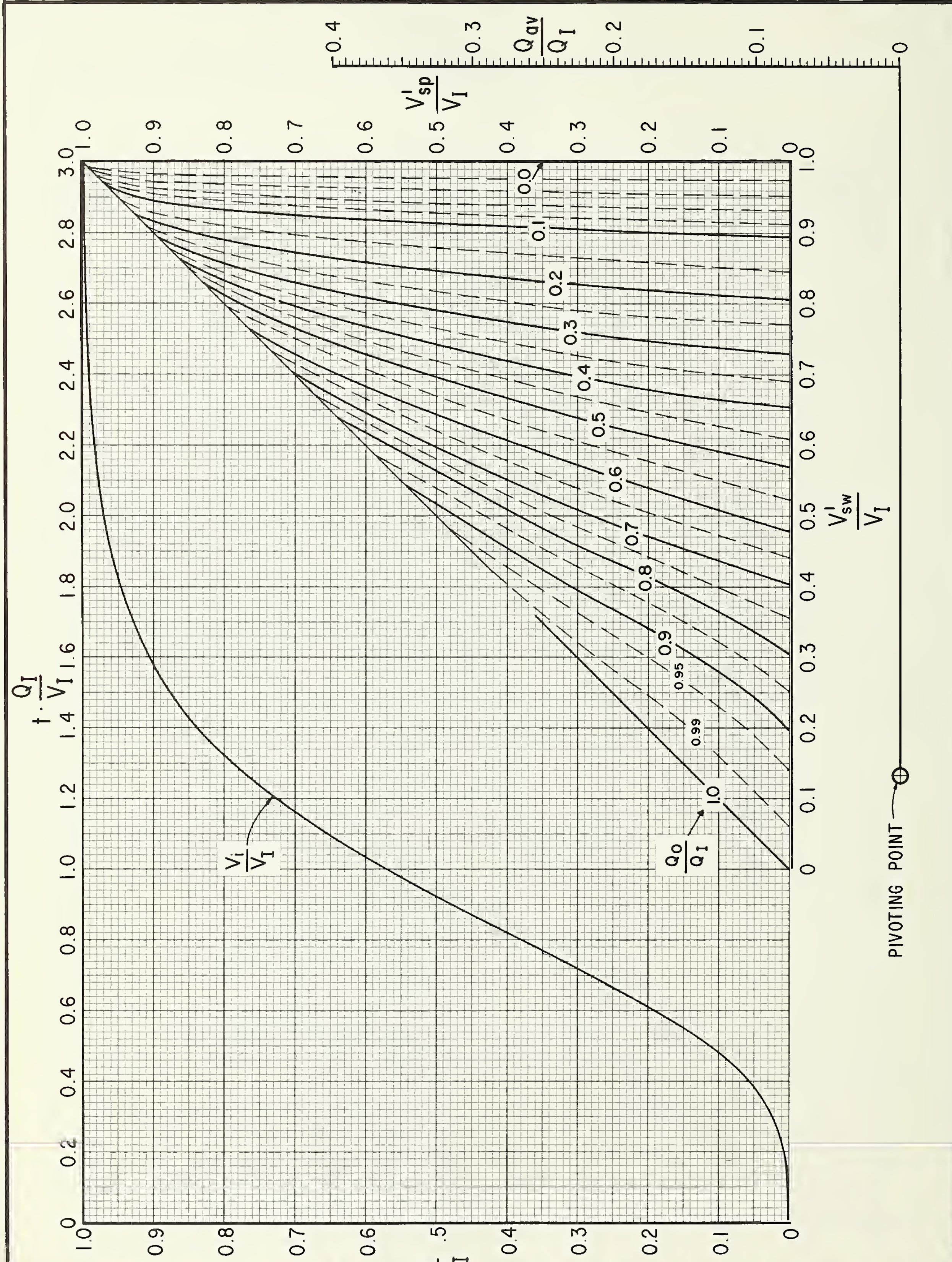


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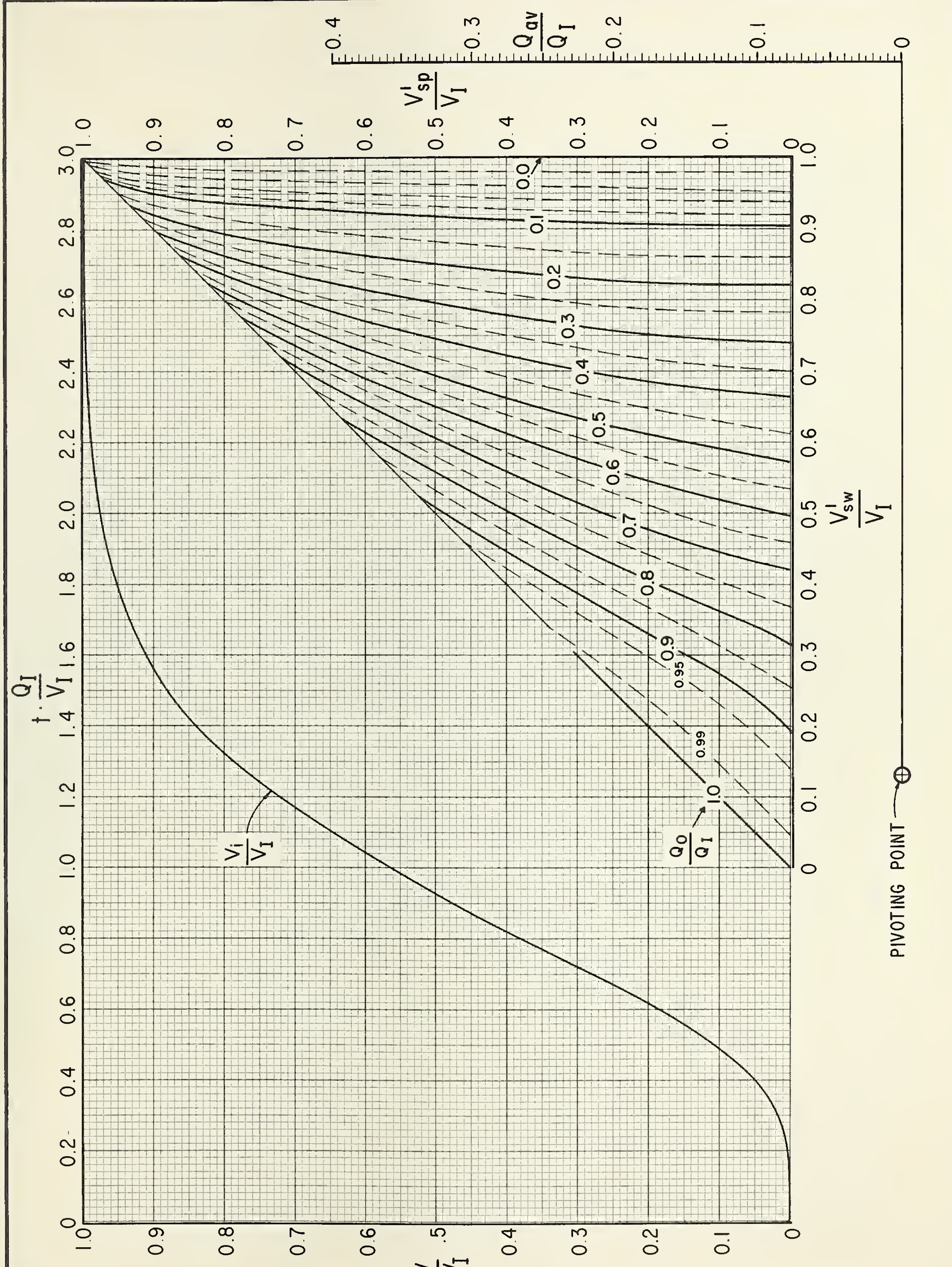


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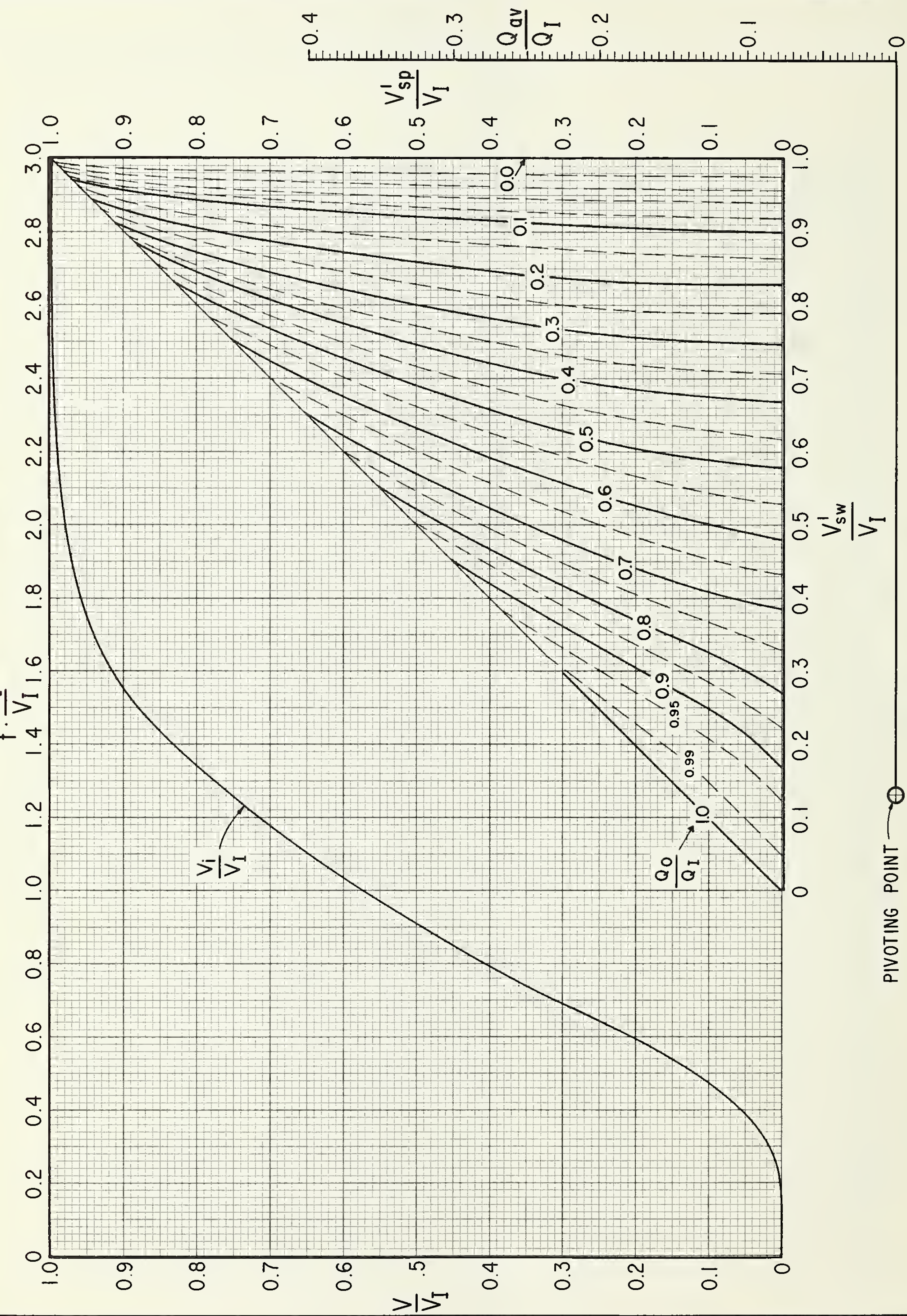


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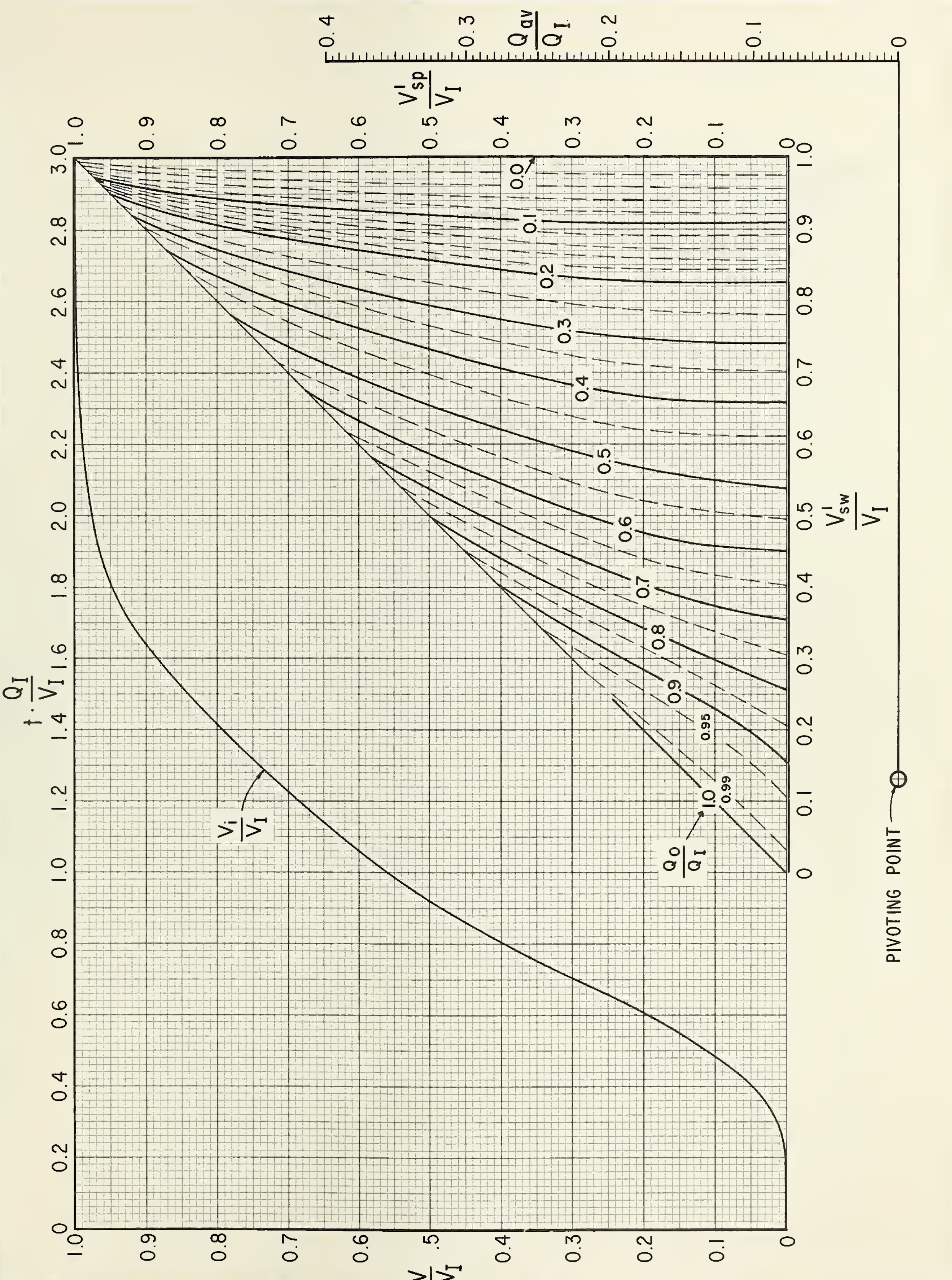


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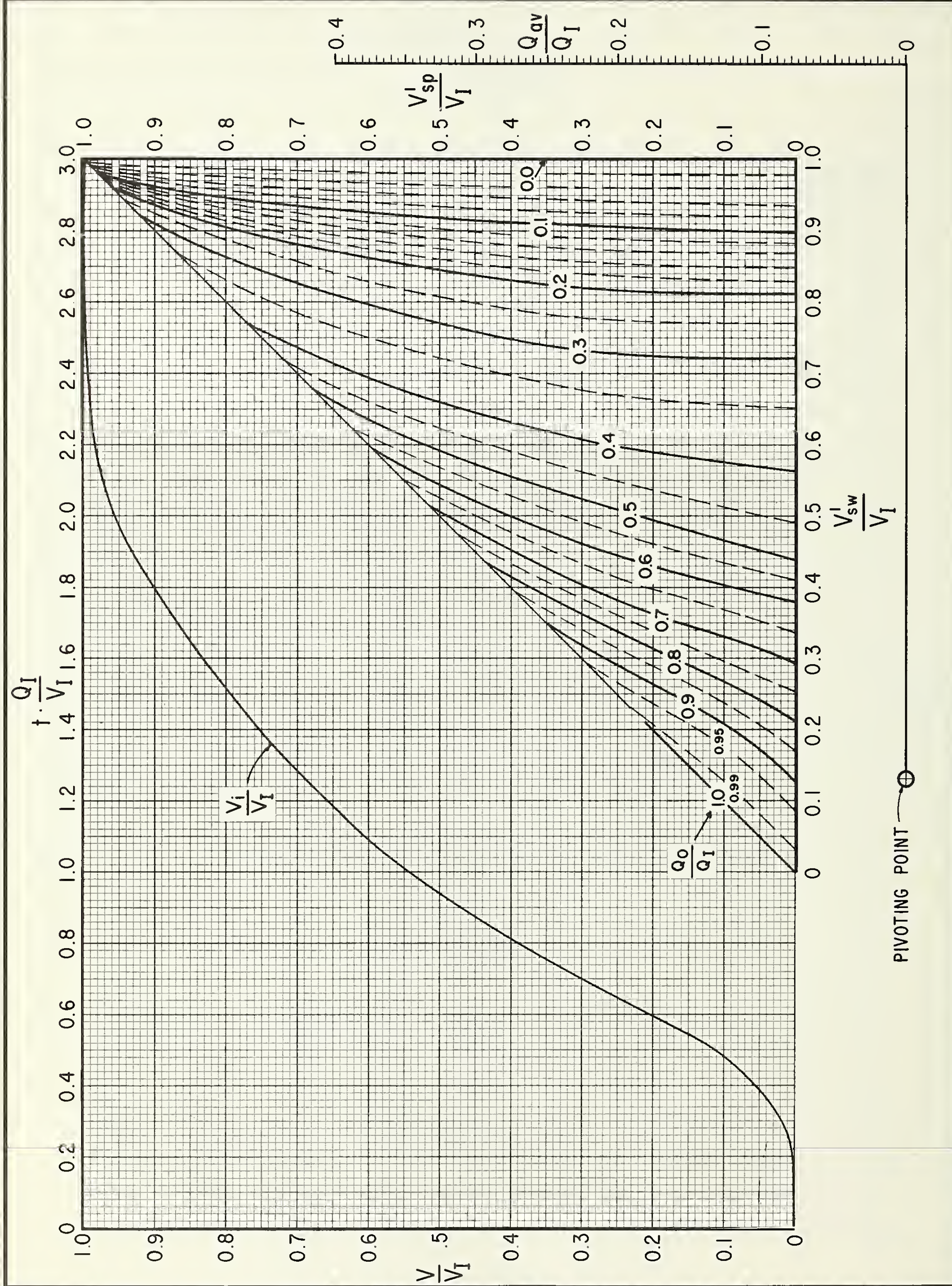


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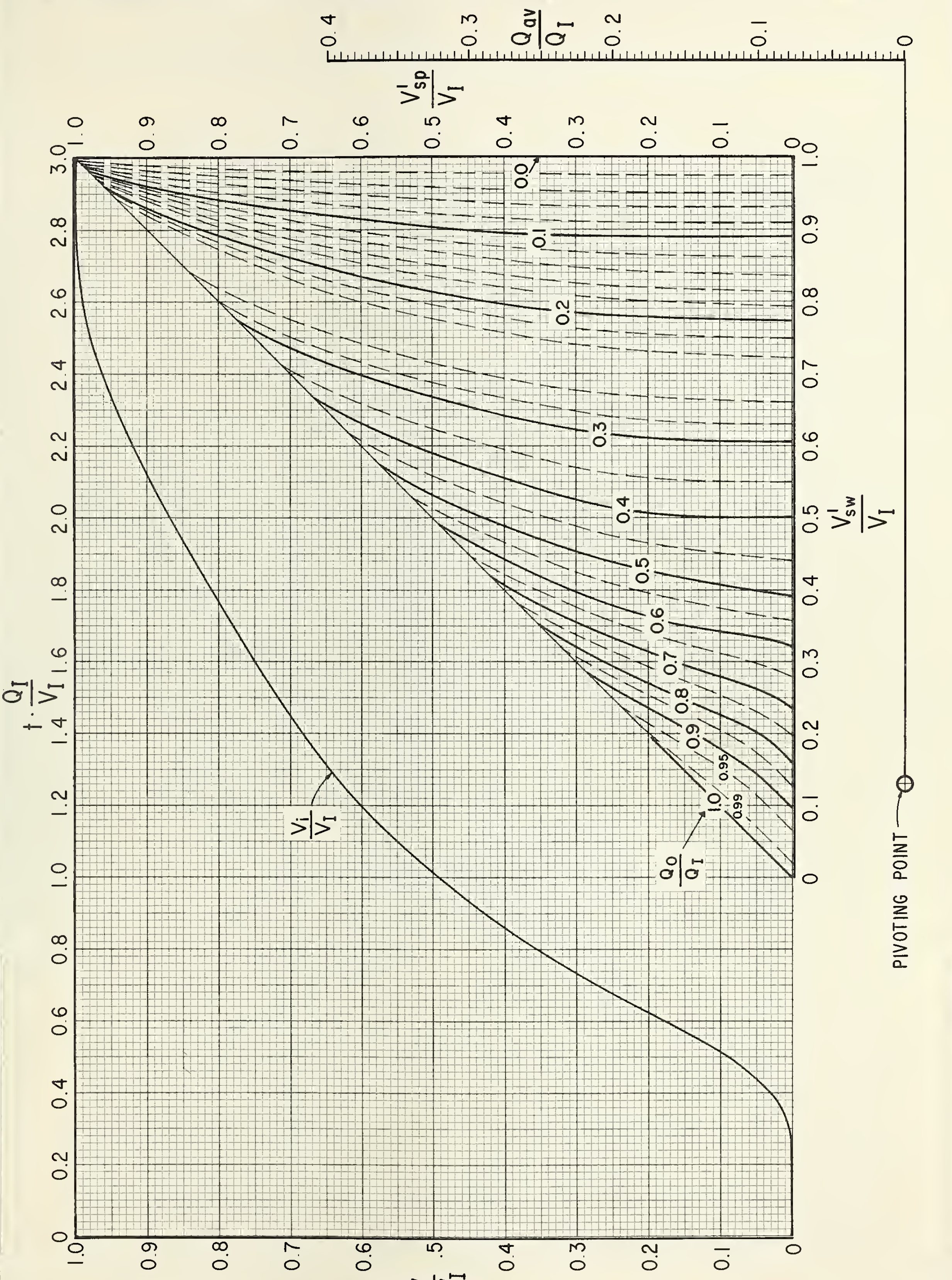


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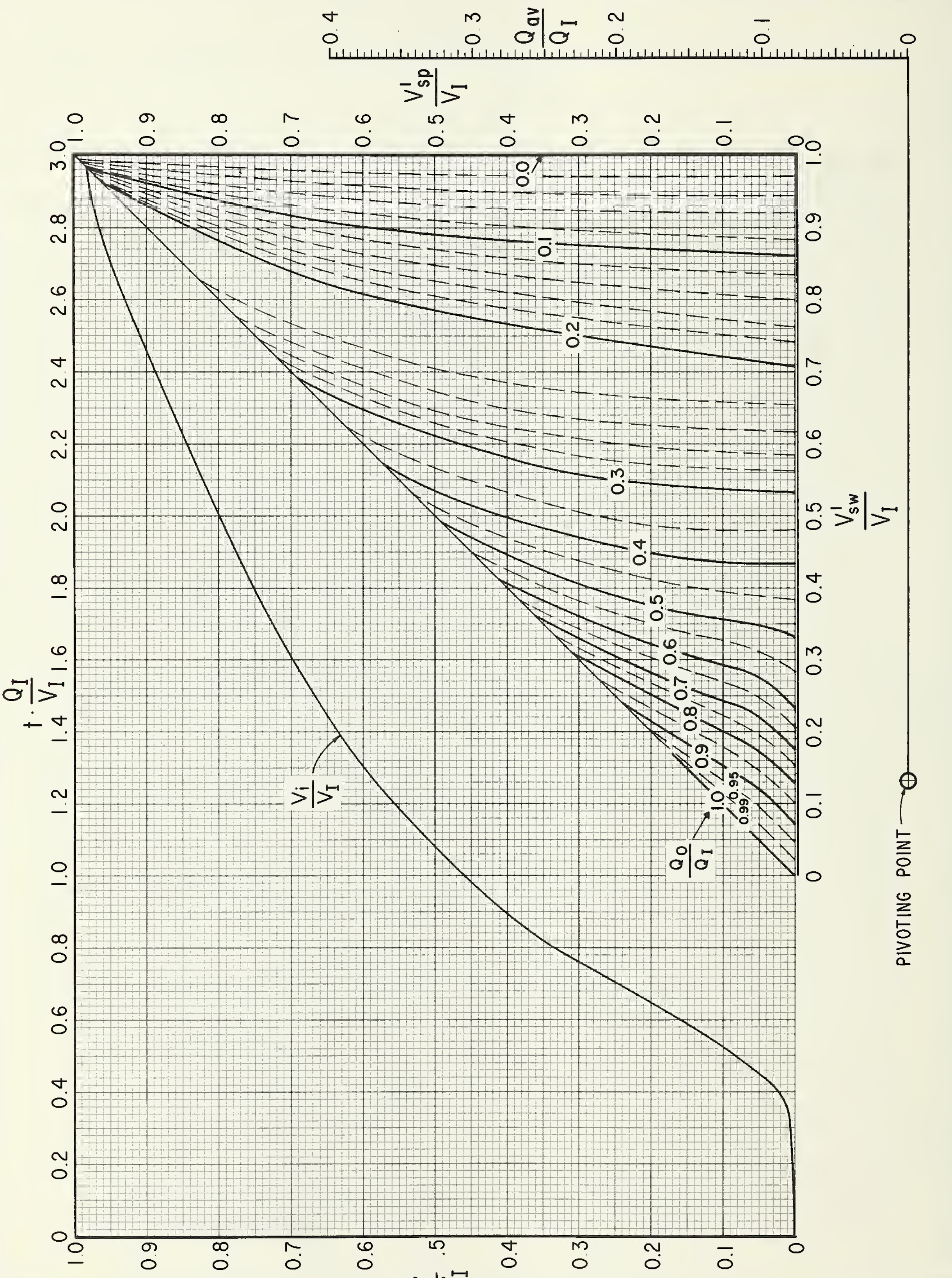


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U. S. DEPARTMENT OF AGRICULTURE
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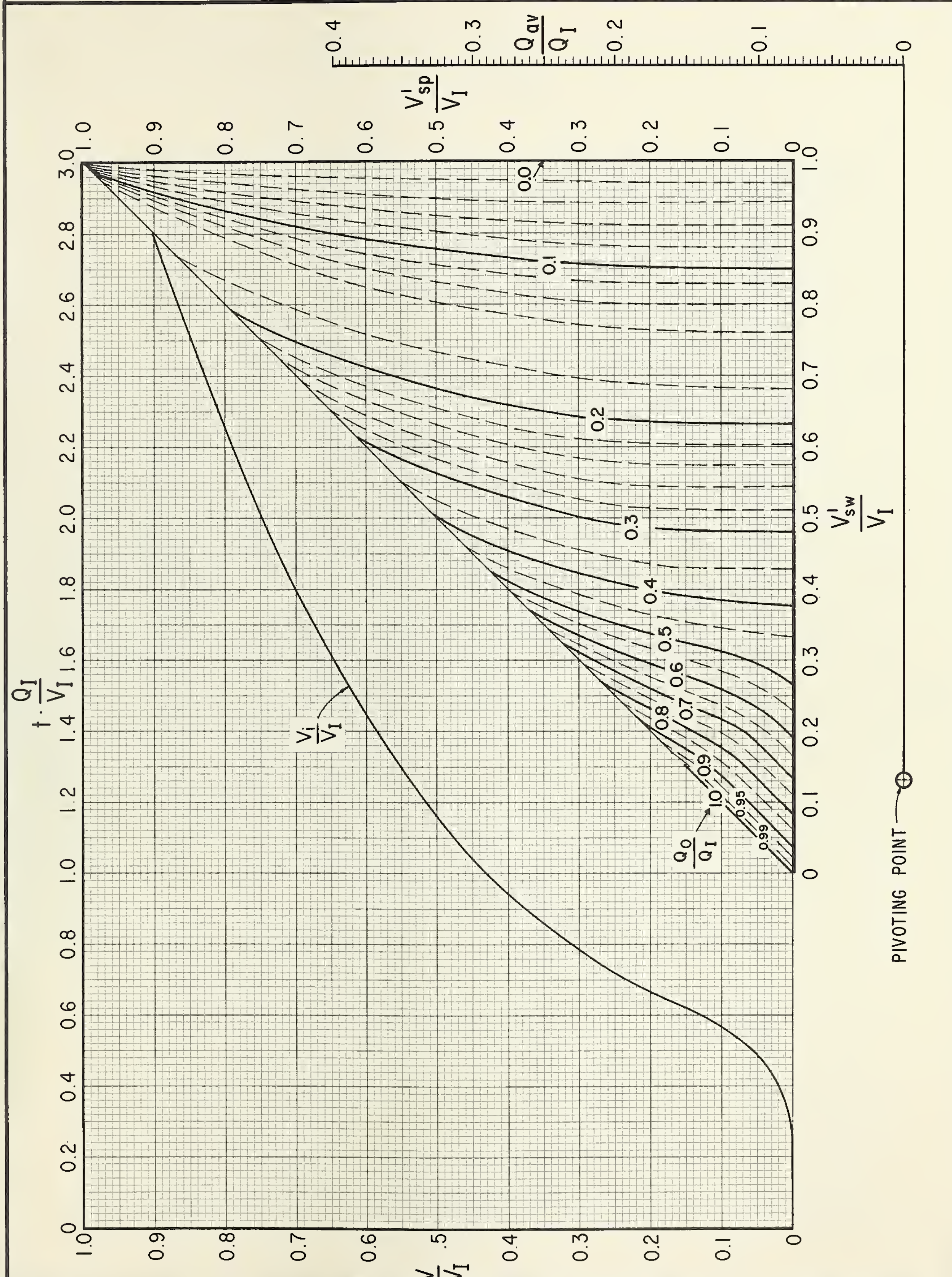
STANDARD DWG. NO. ES-603

SHEET 8 OF 12

DATE November, 1965

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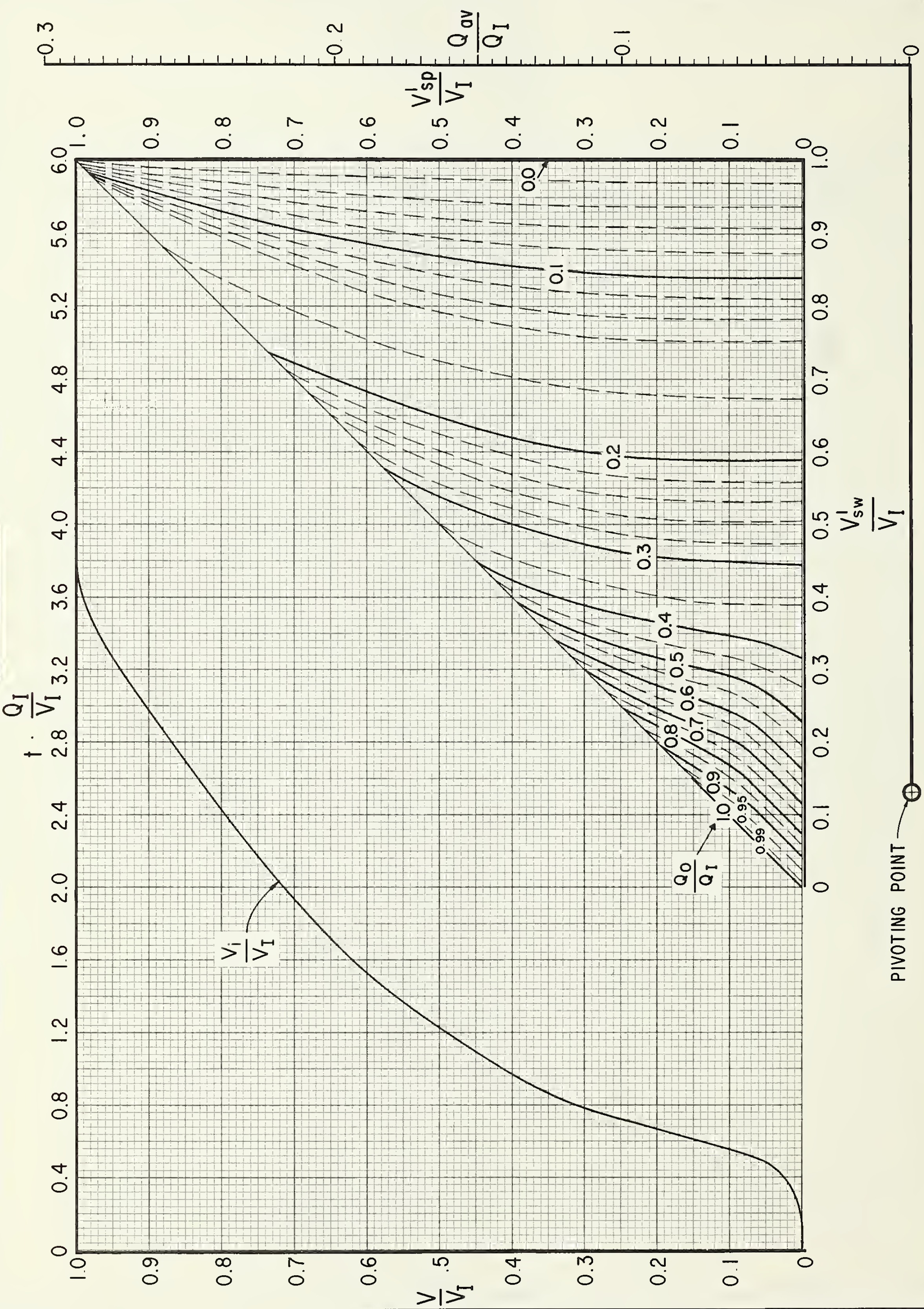
STANDARD DWG. NO.
ES-603
SHEET 9 OF 12
DATE November, 1965




| REFERENCE | U. S. DEPARTMENT OF AGRICULTURE<br>SOIL CONSERVATION SERVICE<br>Prepared By<br>REGIONAL TECHNICAL SERVICE CENTER<br>UPPER DARBY, PENNSYLVANIA | STANDARD DWG. NO.<br>ES-603<br>SHEET 10 OF 12<br>DATE November, 1965 |
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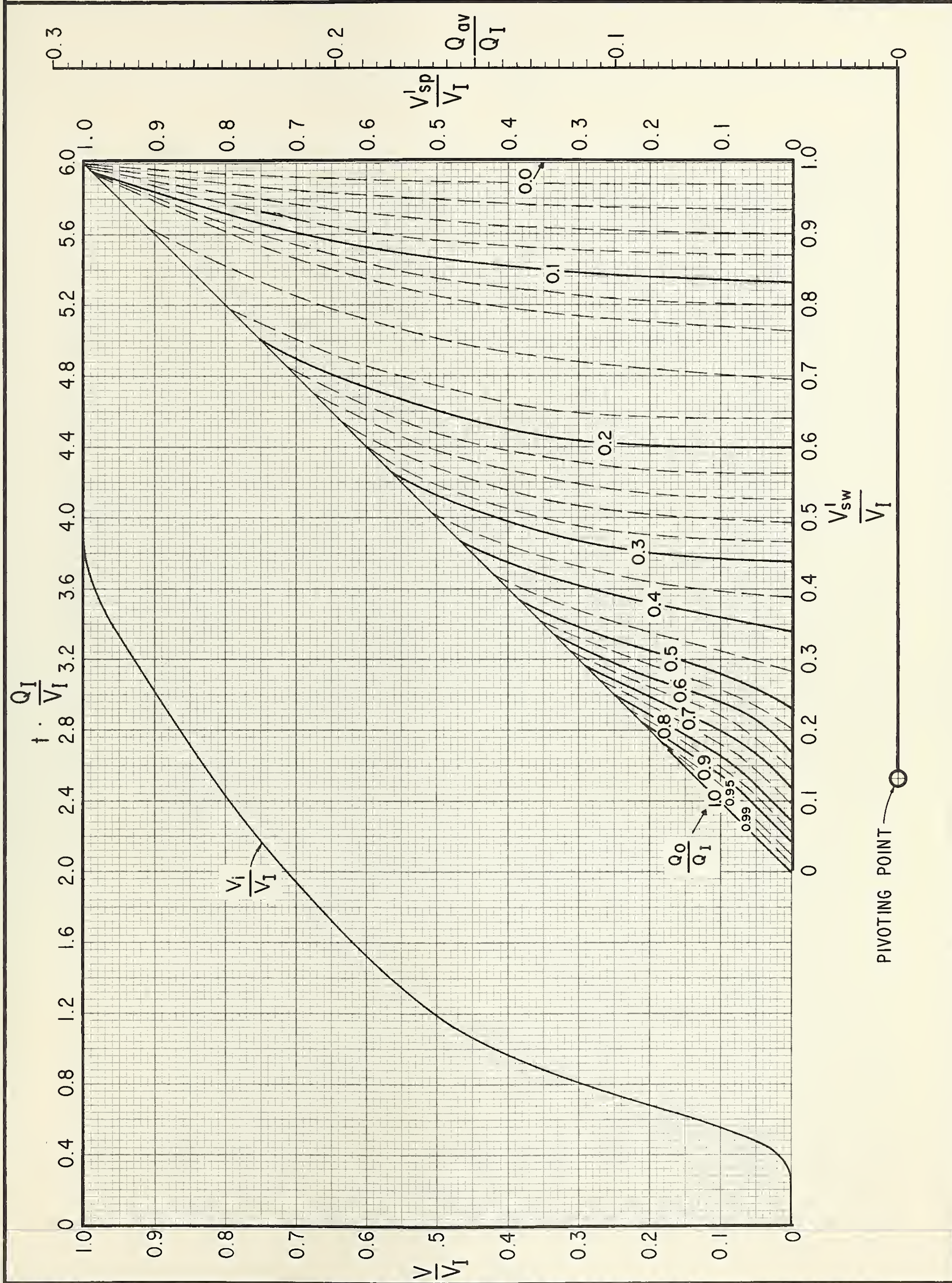


| REFERENCE | U. S. DEPARTMENT OF AGRICULTURE<br>SOIL CONSERVATION SERVICE<br>Prepared By<br>REGIONAL TECHNICAL SERVICE CENTER<br>UPPER DARBY, PENNSYLVANIA | STANDARD DWG. NO.<br>ES-603<br>SHEET 11 OF 12<br>DATE November, 1965 |
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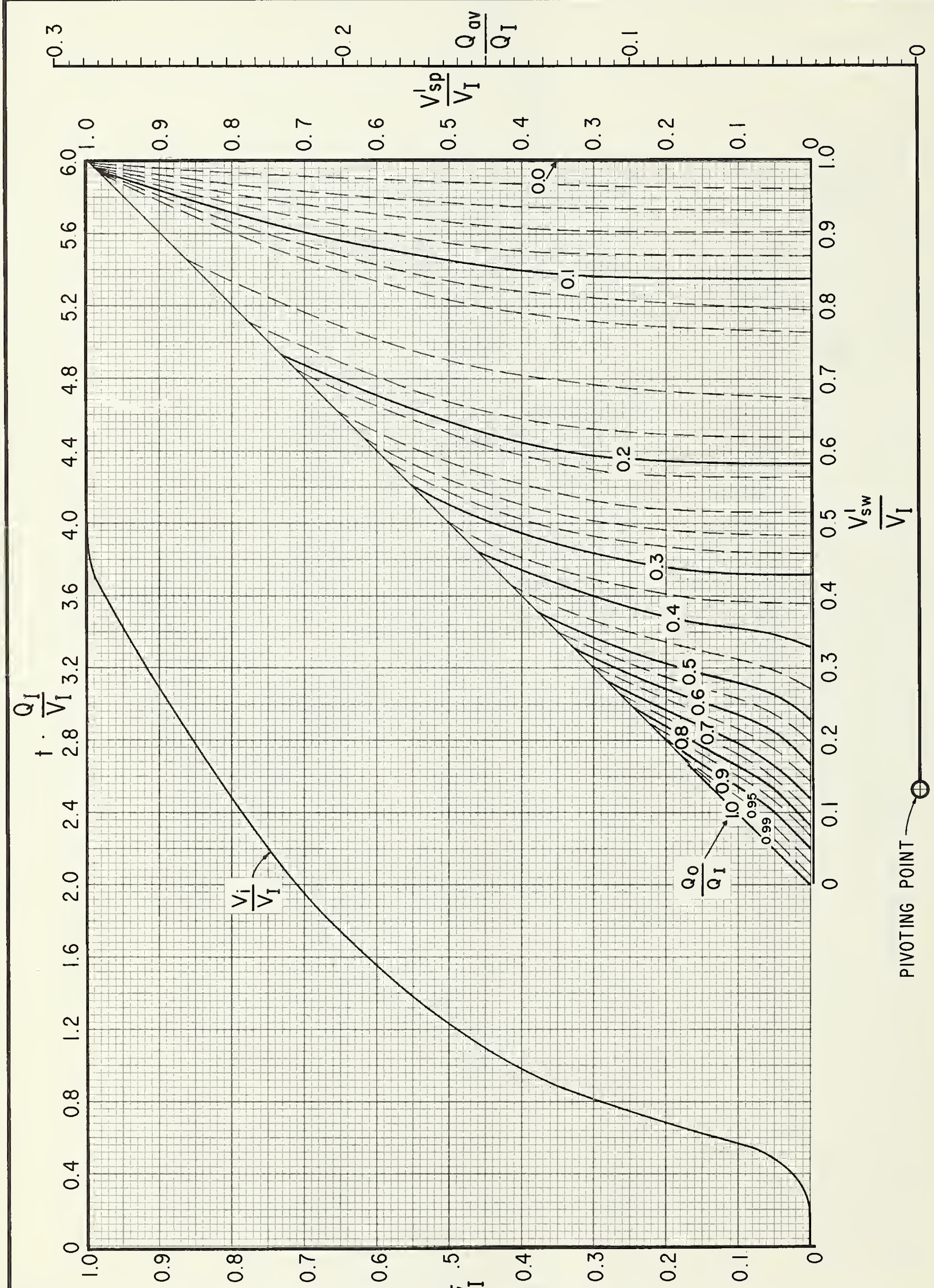


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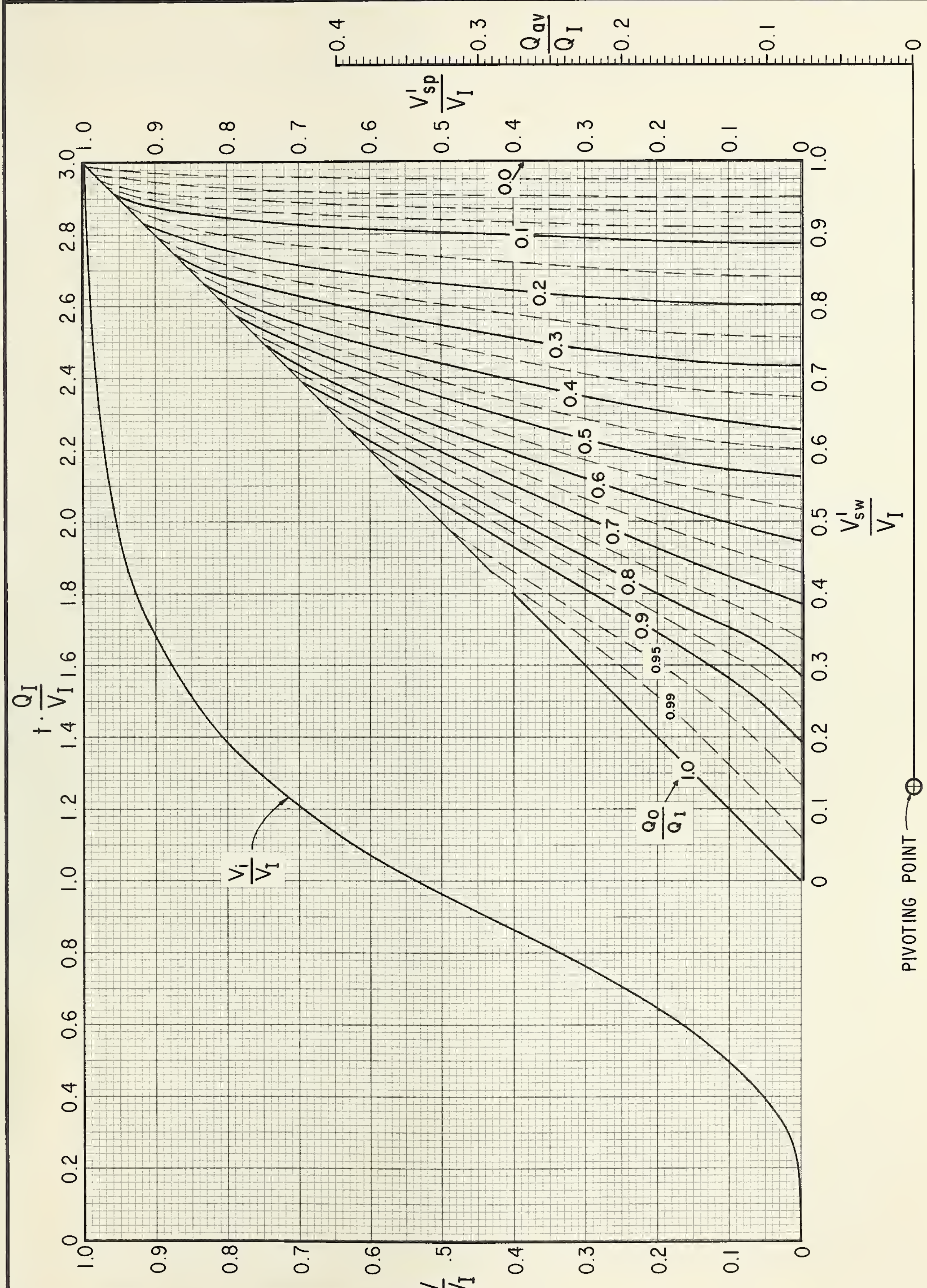
STANDARD DWG. NO.
ES-603
SHEET 12 OF 12
DATE November, 1965

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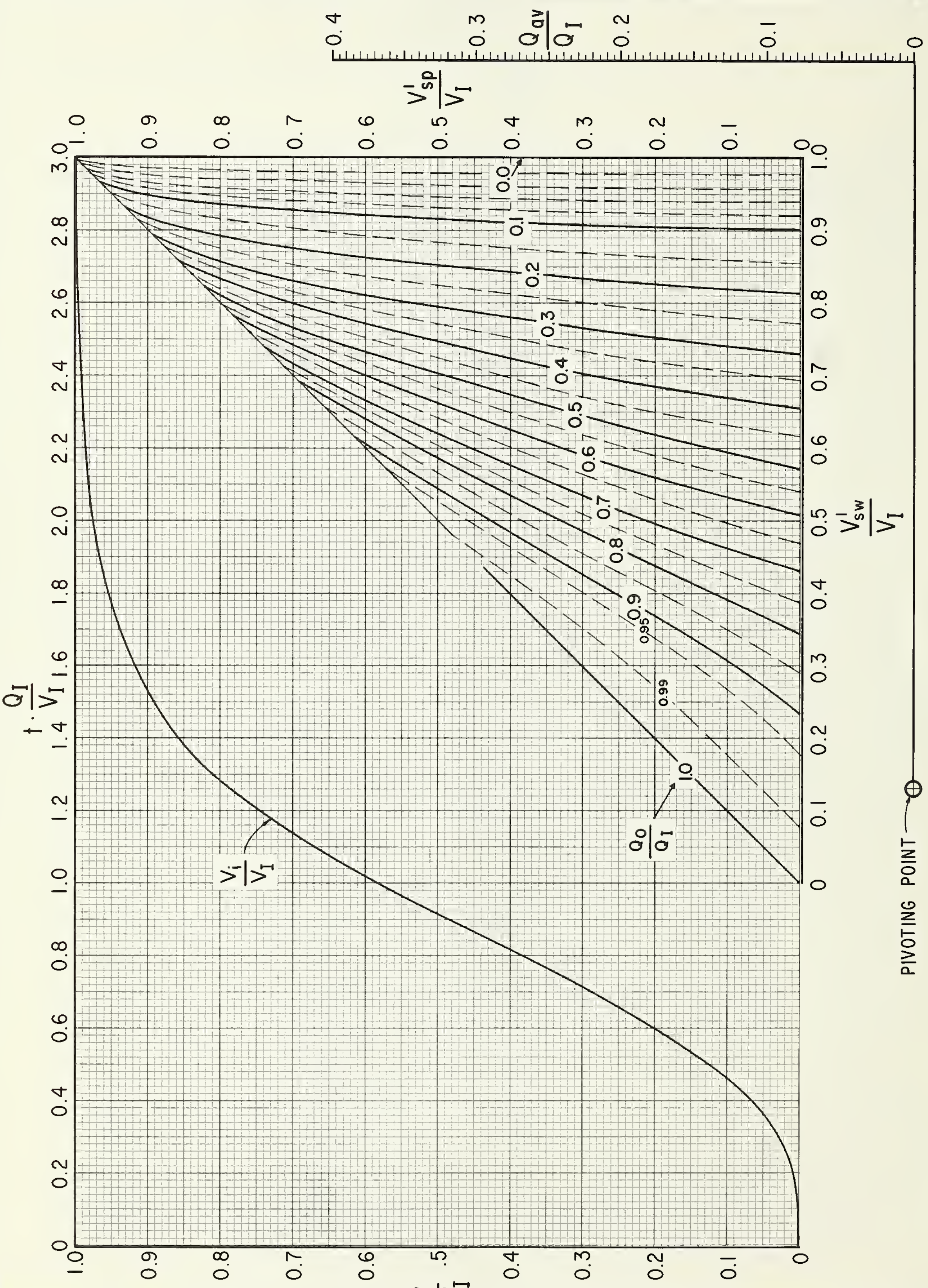
STANDARD DWG NO.
ES-604
SHEET 1 OF 11
DATE November, 1965

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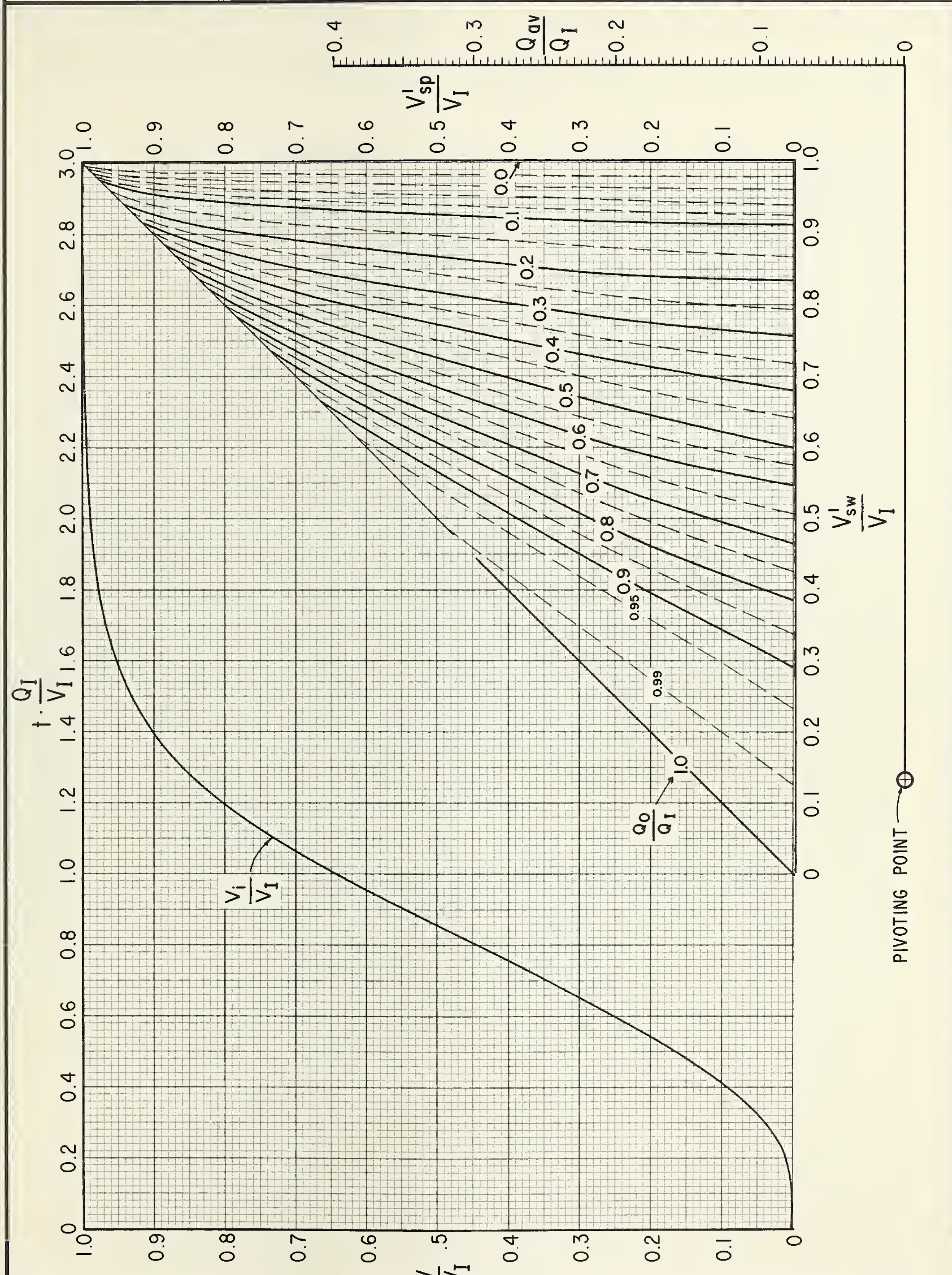
STANDARD DWG. NO.
ES-604
SHEET 2 OF 11
DATE November, 1965




| REFERENCE | U. S. DEPARTMENT OF AGRICULTURE<br>SOIL CONSERVATION SERVICE<br>Prepared By<br>REGIONAL TECHNICAL SERVICE CENTER<br>UPPER DARBY, PENNSYLVANIA | STANDARD DWG. NO.<br>ES-604<br>SHEET 3 OF 11<br>DATE November, 1965 |
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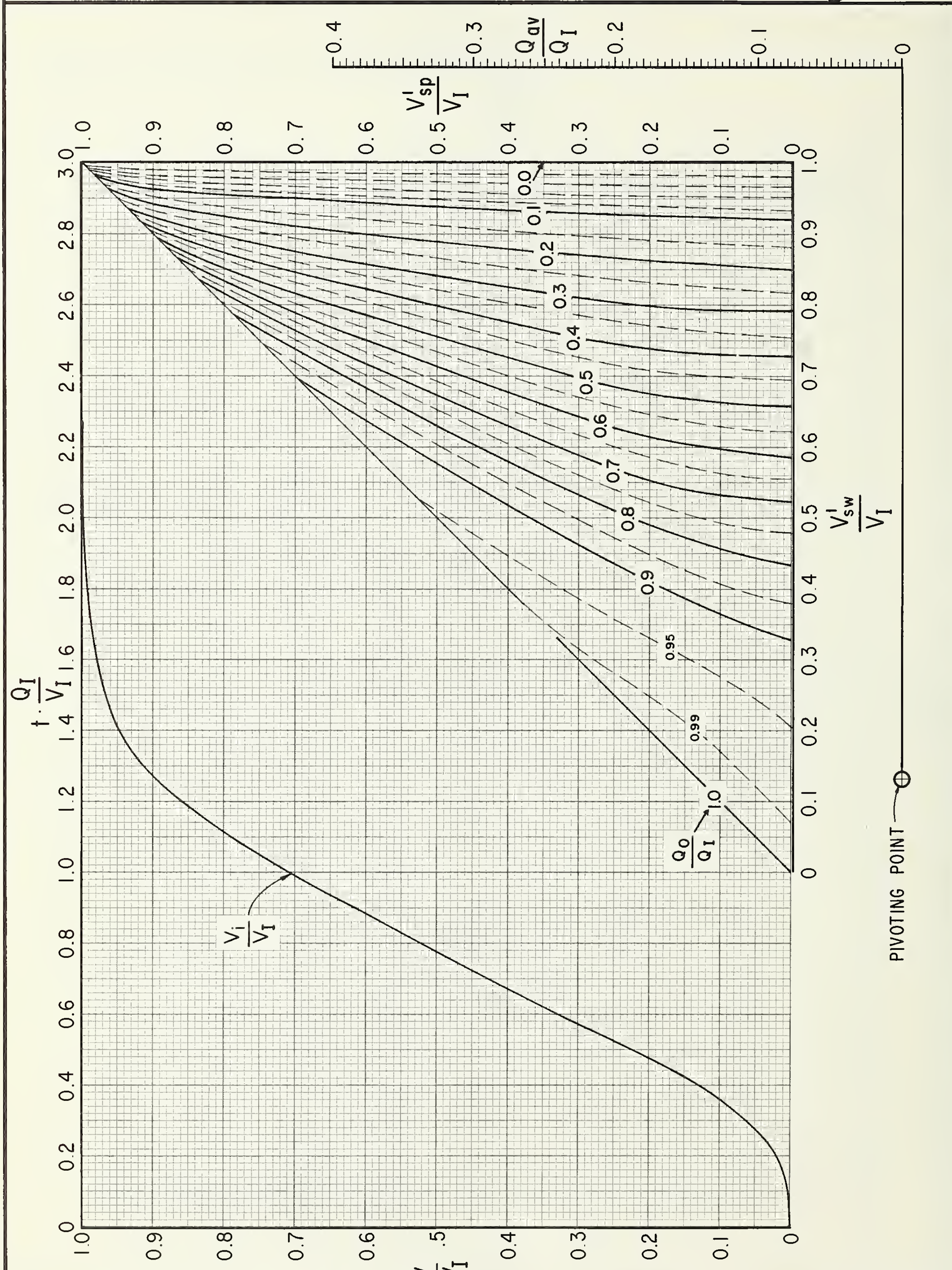


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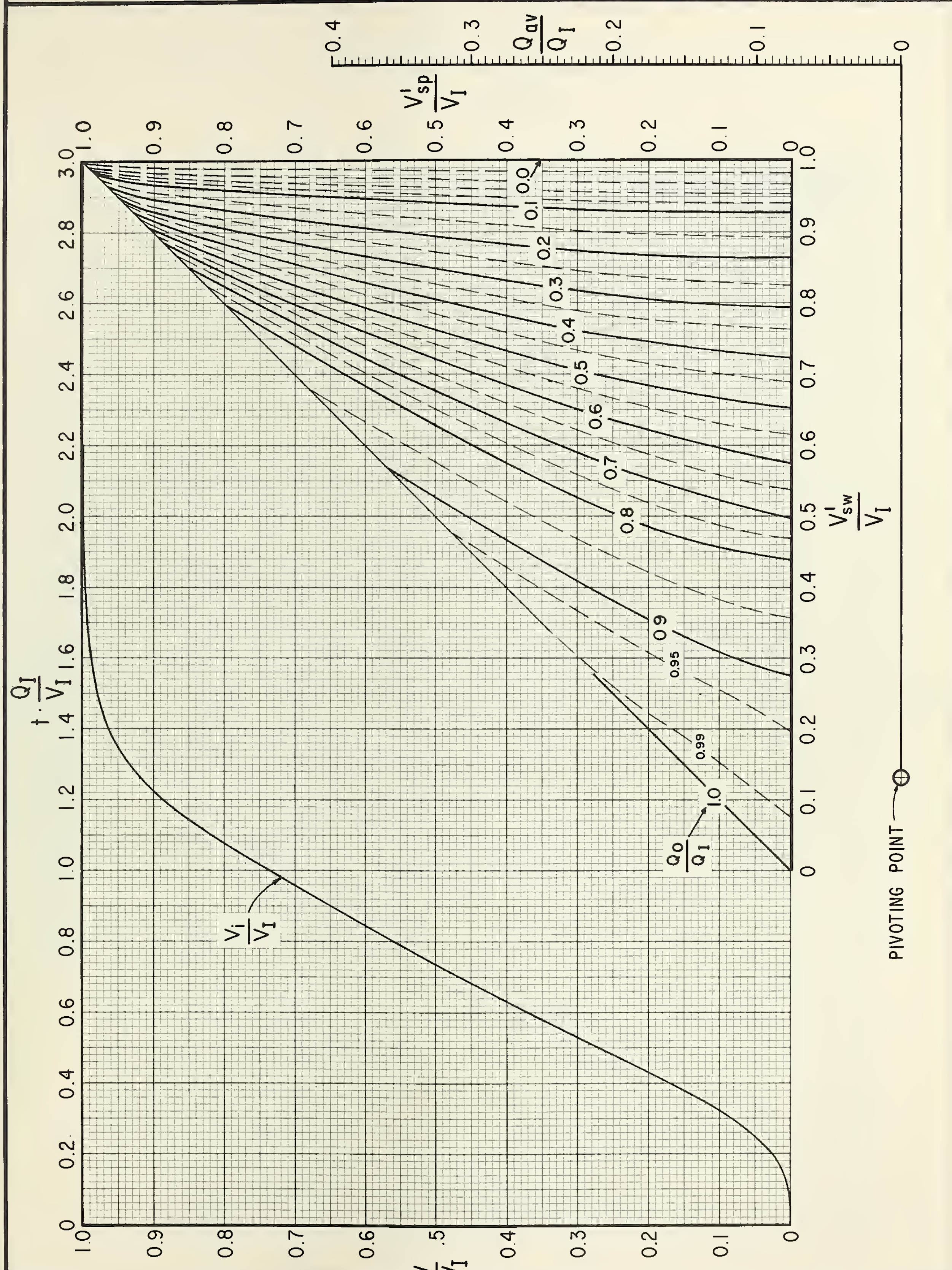
ES-604
SHEET 4 OF 11
DATE November, 1965

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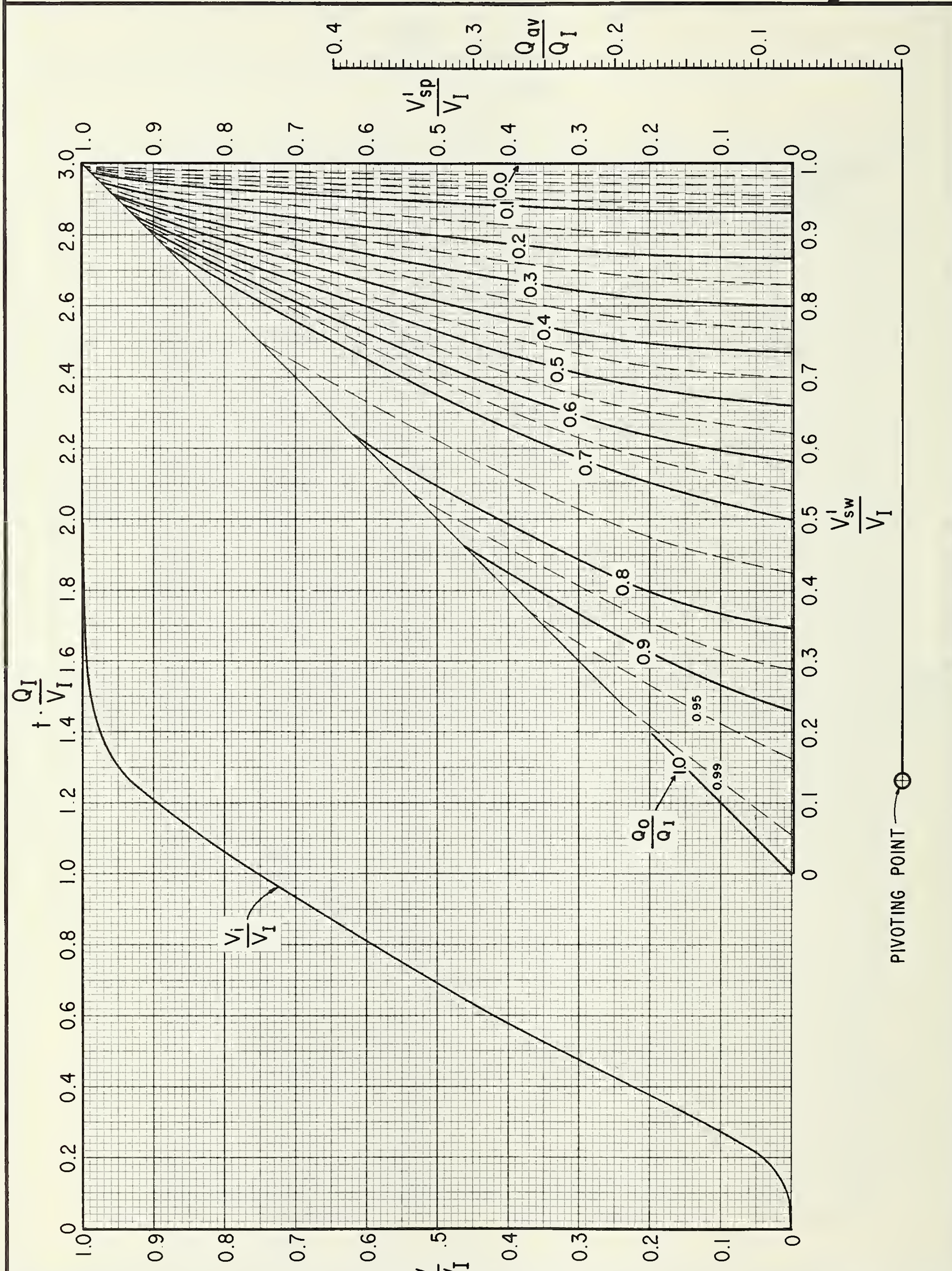
ES-604
SHEET 5 OF 11
DATE November, 1965

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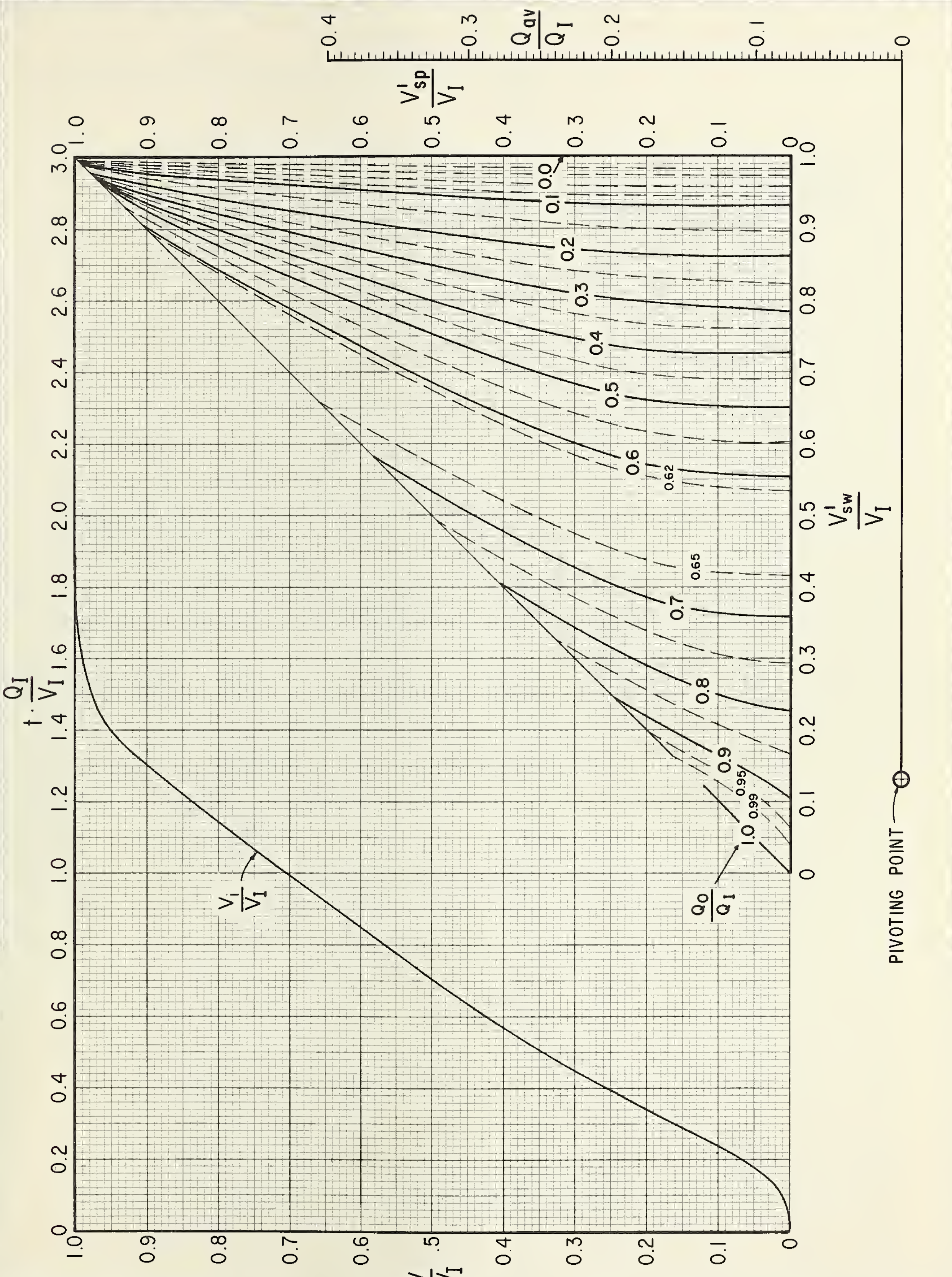
ES-604
SHEET 6 OF 11
DATE November, 1965

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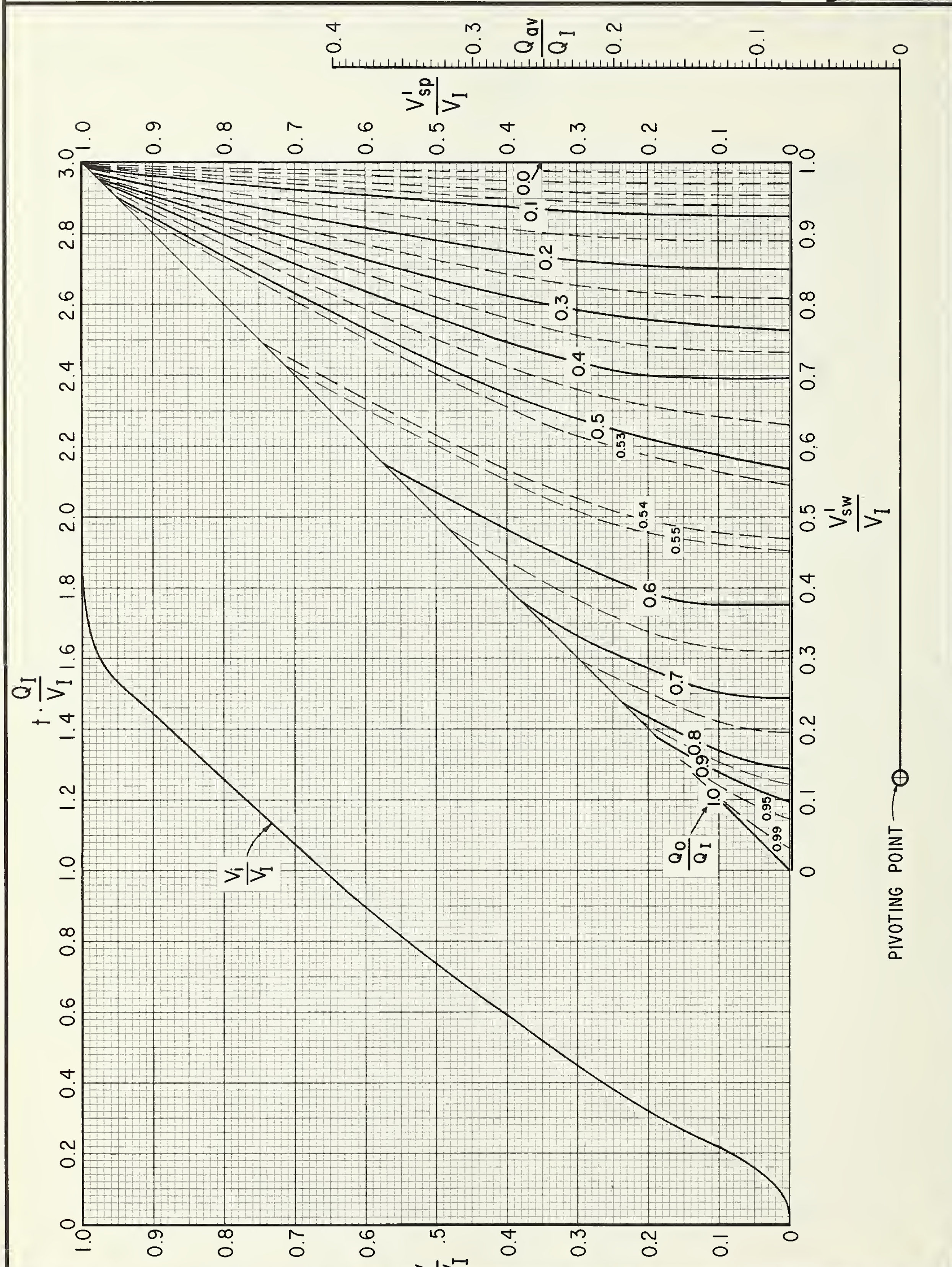
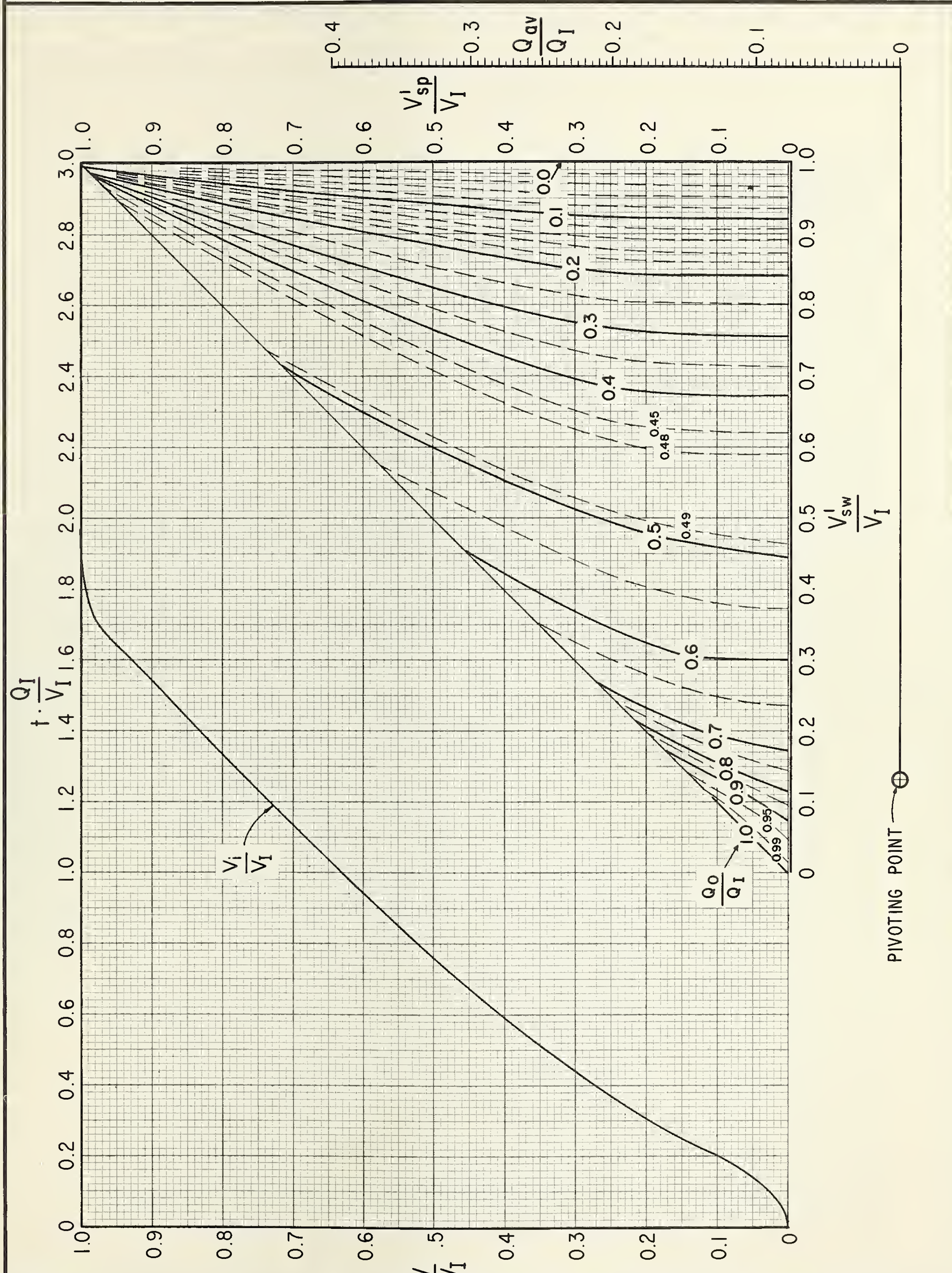
ES-604
SHEET 7 OF 11
DATE November, 1965

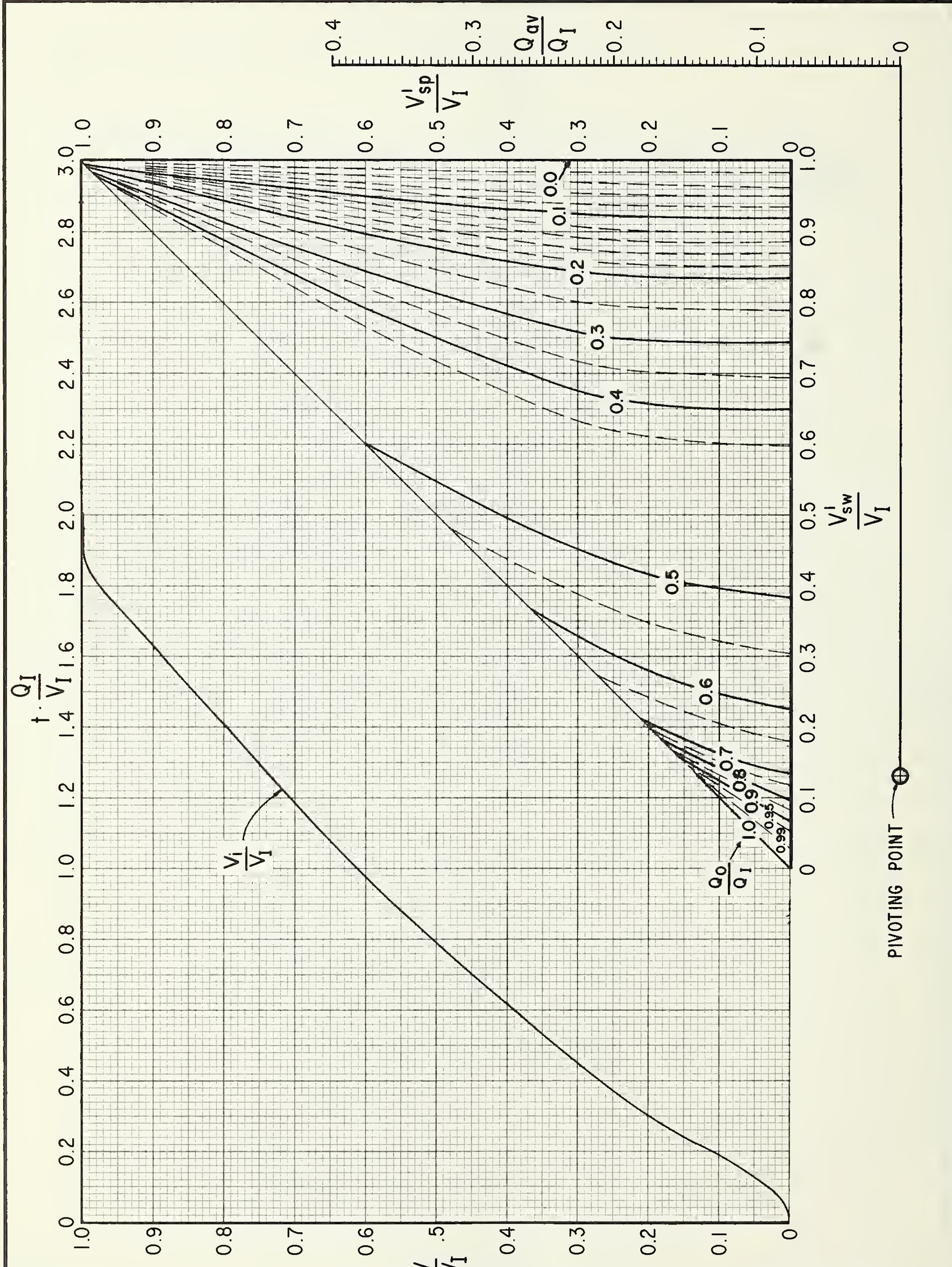

Qav/QI
V'sp/VI
V'sw/VI
t · QI/VI
V/VI
Vi/VI
Qo/QI
PIVOTING POINT




| REFERENCE | U. S. DEPARTMENT OF AGRICULTURE<br>SOIL CONSERVATION SERVICE<br>Prepared By<br>REGIONAL TECHNICAL SERVICE CENTER<br>UPPER DARBY, PENNSYLVANIA | STANDARD DWG. NO.<br>ES-604<br>SHEET 9 OF 11<br>DATE November, 1965 |
|---|---|---|

# UD METHOD: RESERVOIR FLOOD ROUTING CHARTS



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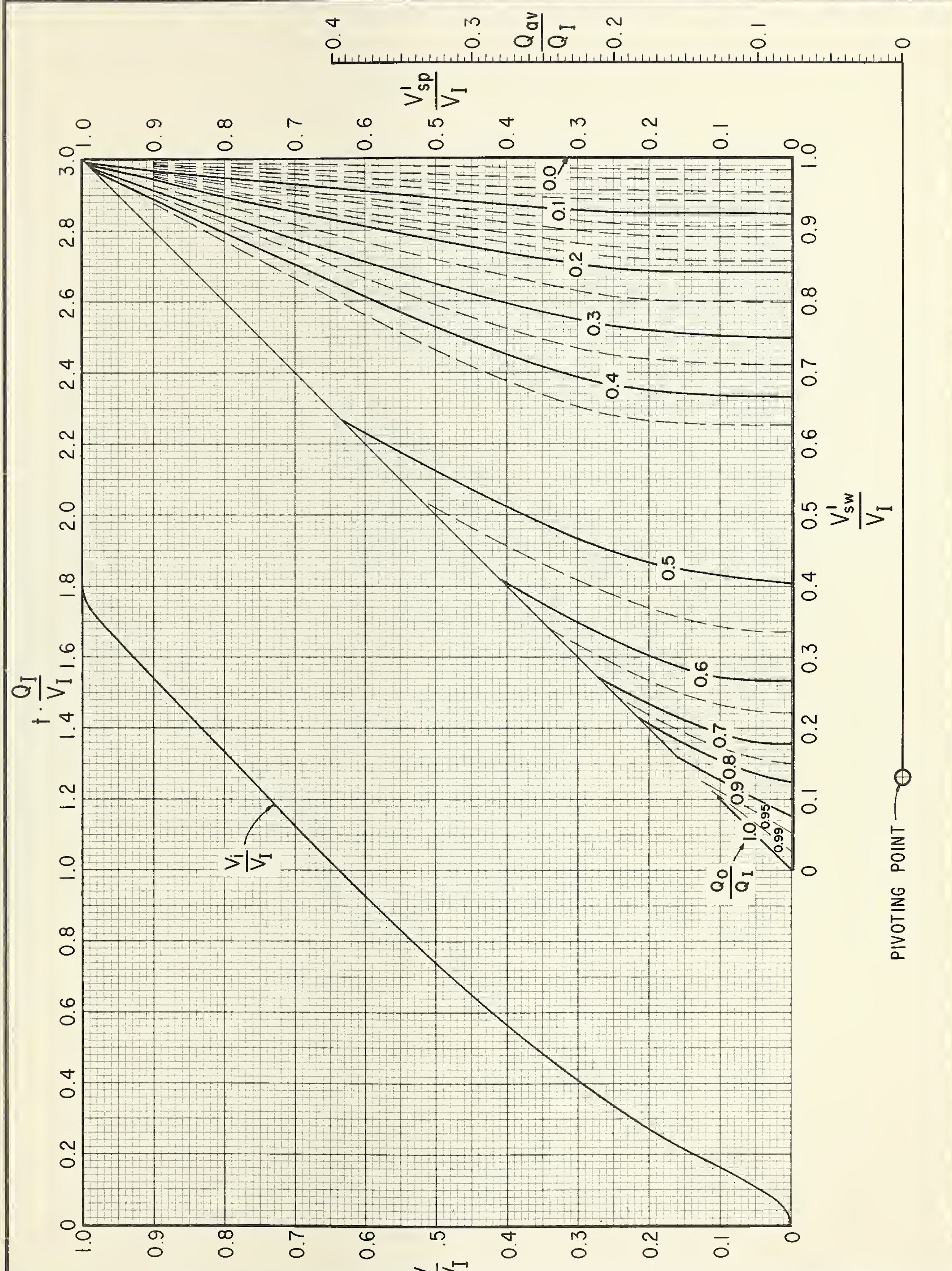
STANDARD DWG. NO
ES-604
SHEET 10 OF 11
DATE November, 1965

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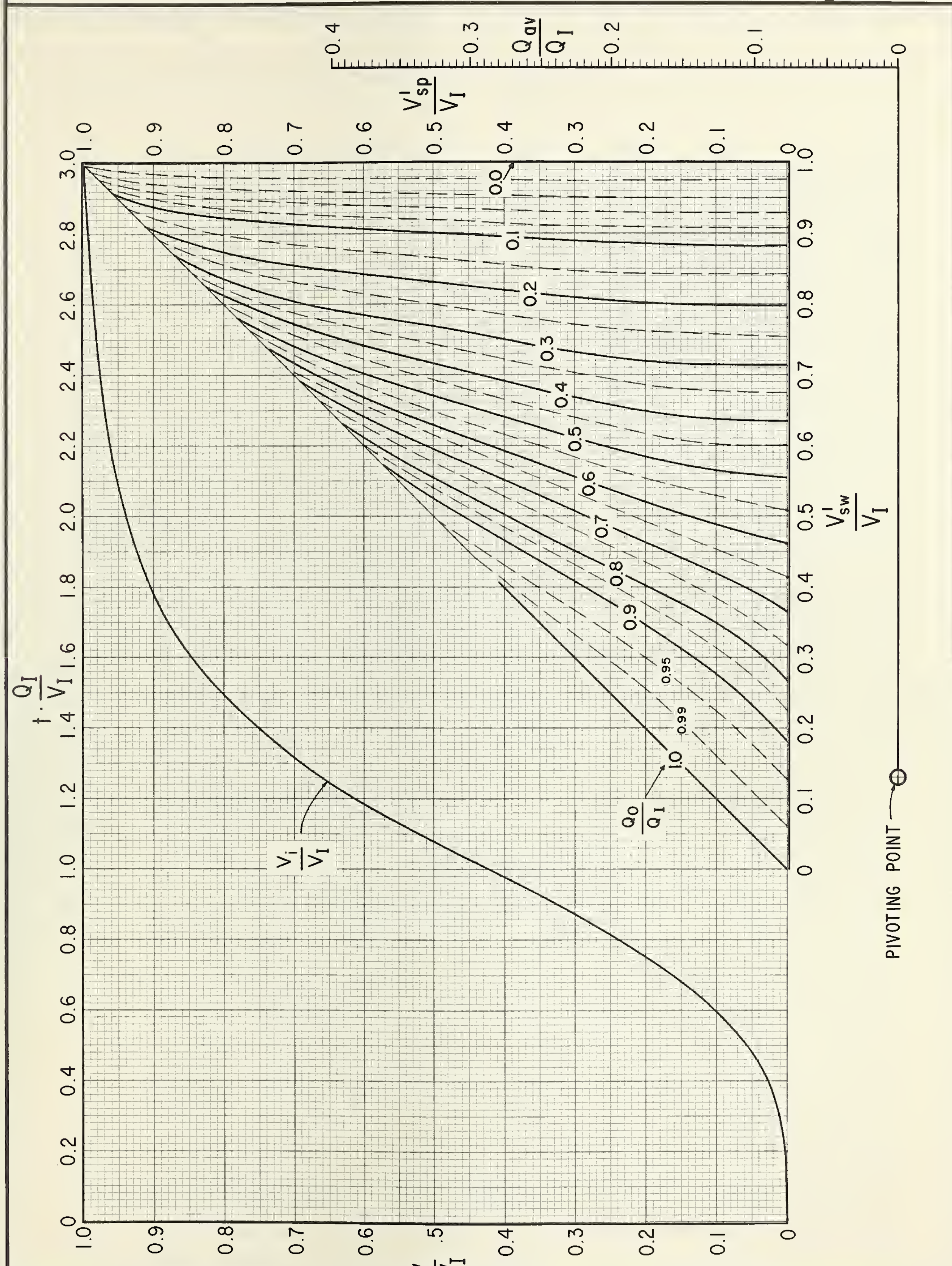


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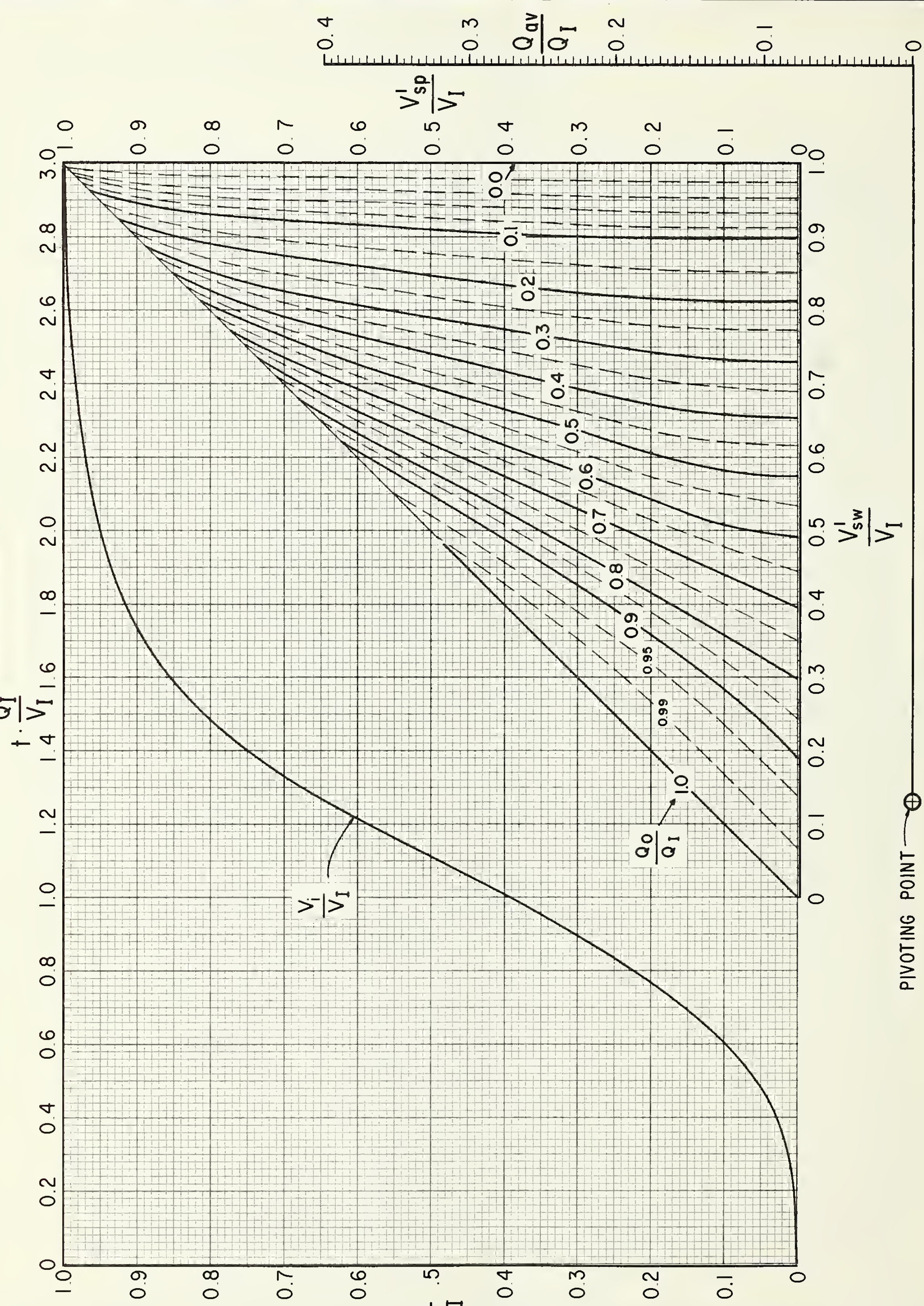
STANDARD DWG. NO.
ES-605
SHEET 1 OF 11
DATE November, 1965

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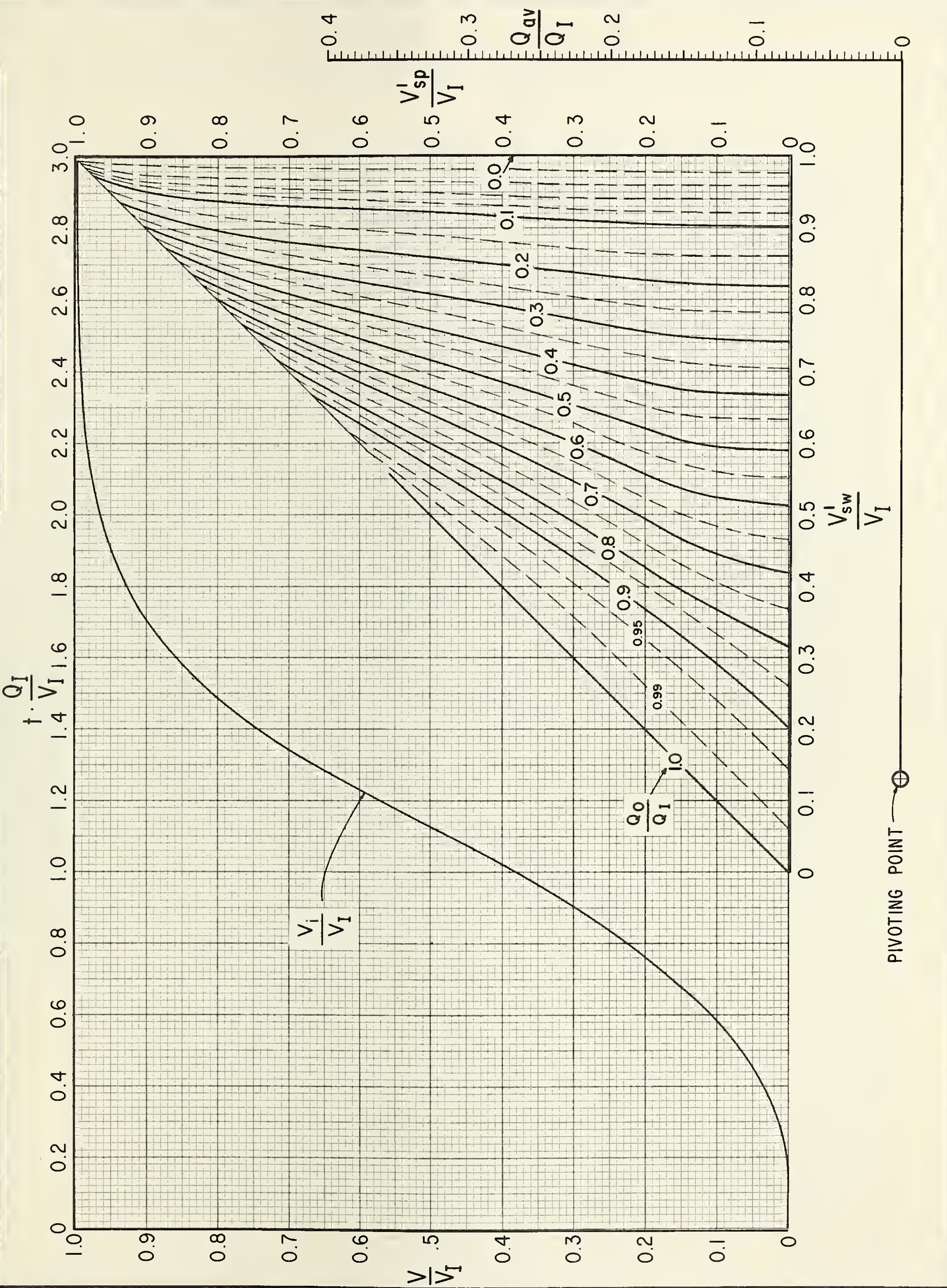
ES-605
SHEET 2 OF 11
DATE November, 1965

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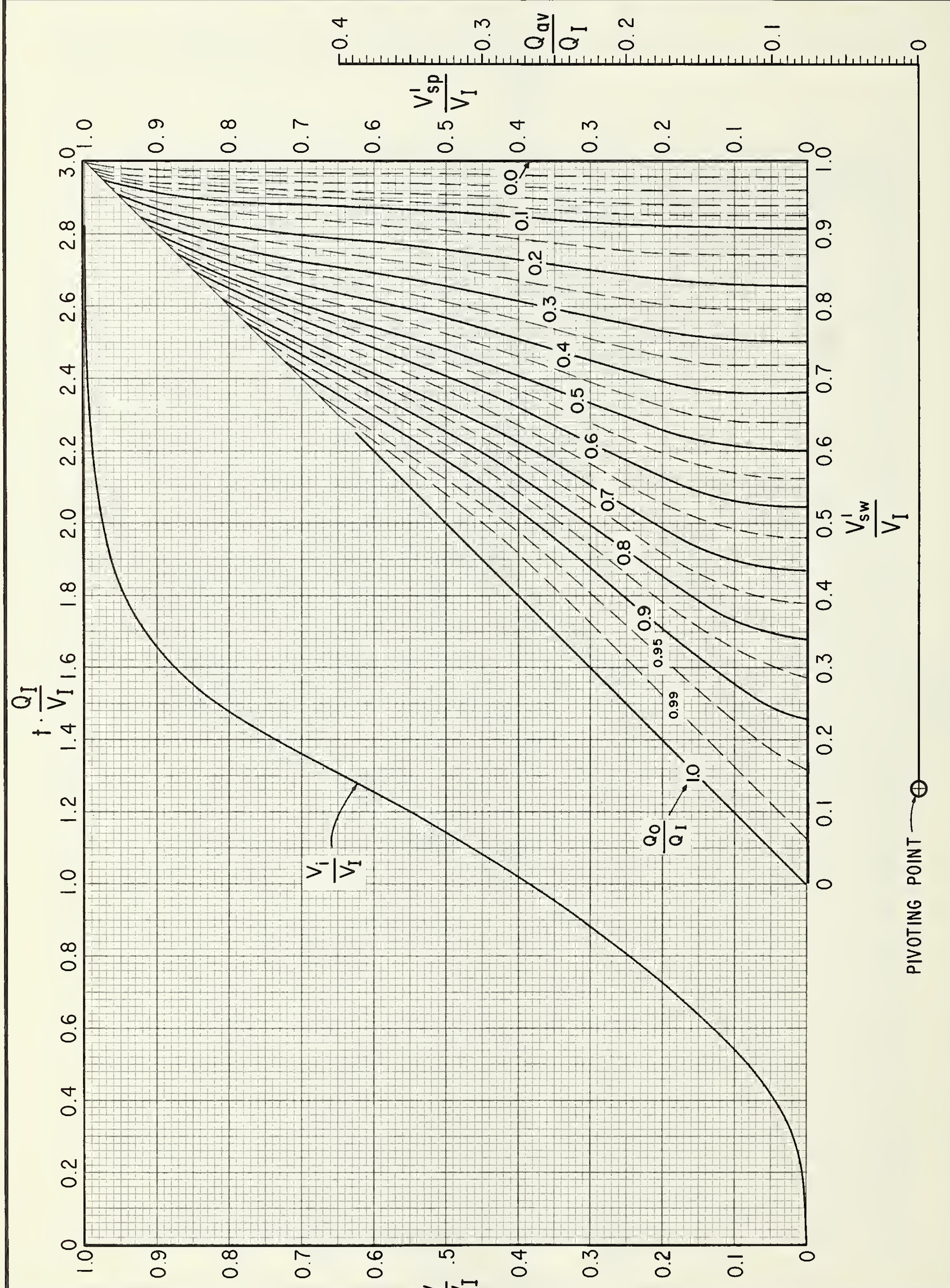
STANDARD DWG. NO.
ES-605
SHEET 3 OF 11
DATE November, 1965

# UD METHOD: RESERVOIR FLOOD ROUTING CHARTS

5/3




| REFERENCE | U. S. DEPARTMENT OF AGRICULTURE<br>SOIL CONSERVATION SERVICE<br>Prepared By<br>REGIONAL TECHNICAL SERVICE CENTER<br>UPPER DARBY, PENNSYLVANIA | STANDARD DWG. NO.<br>ES-605<br>SHEET 4 OF 11<br>DATE November, 1965 |
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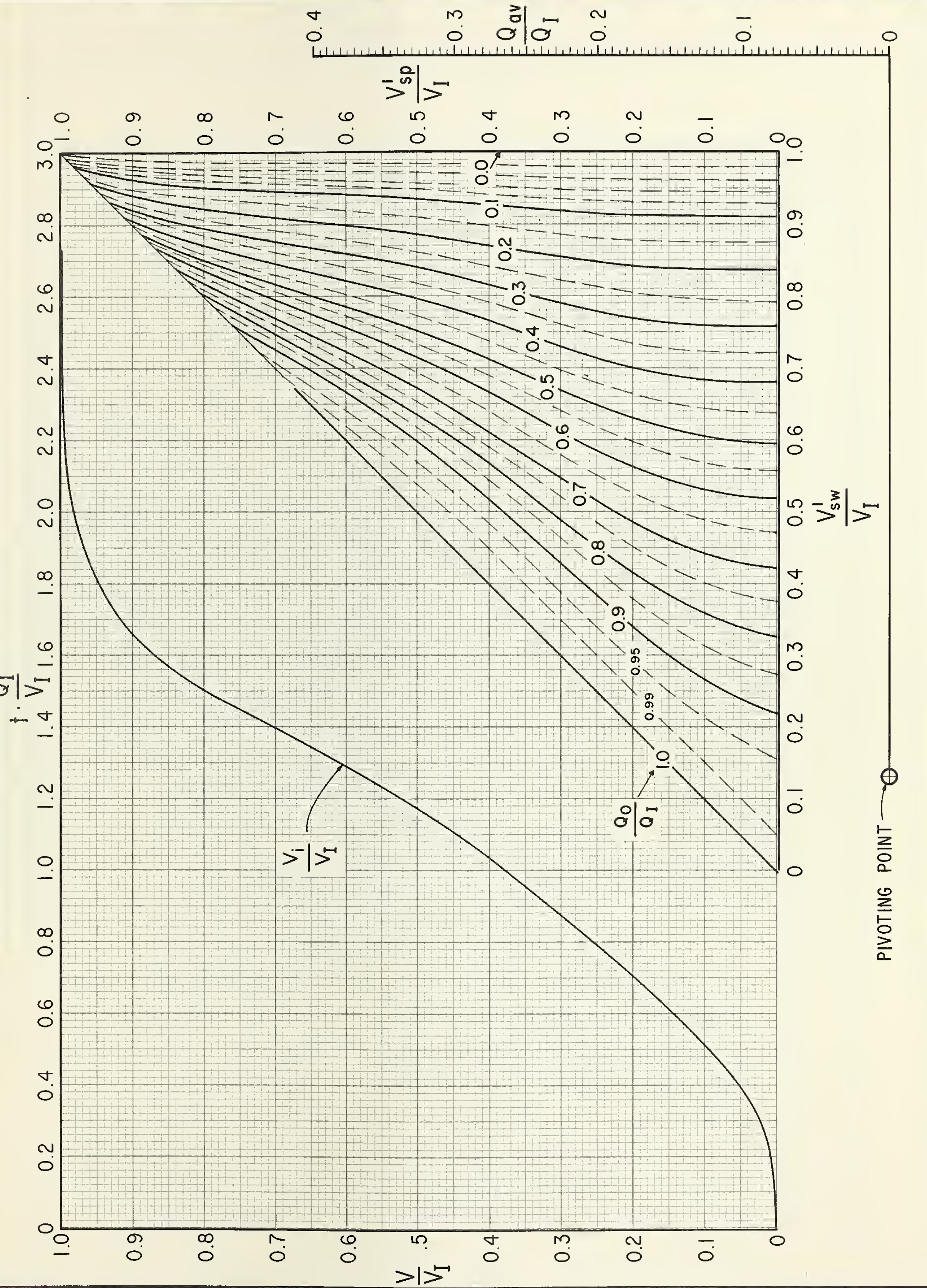


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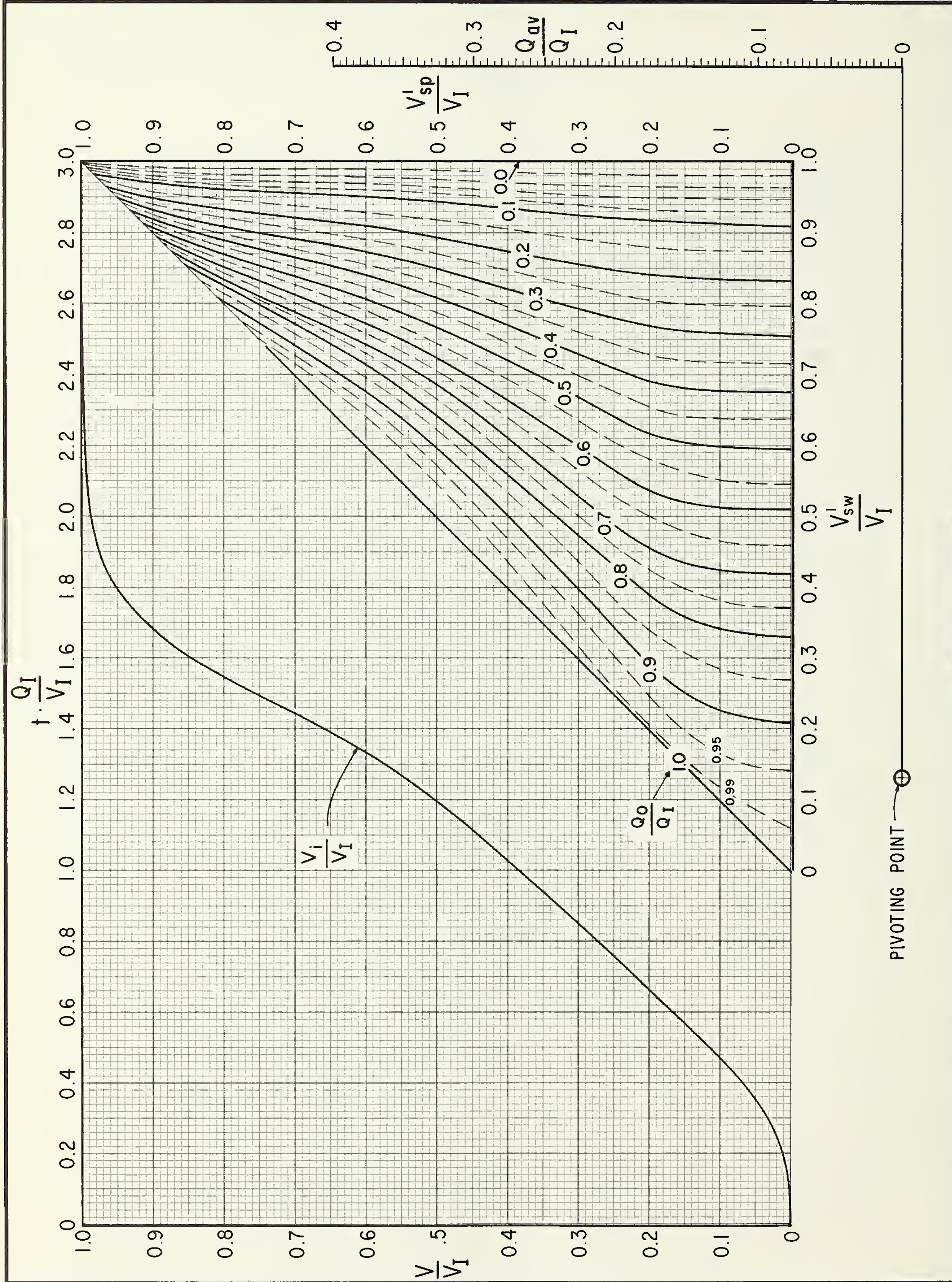


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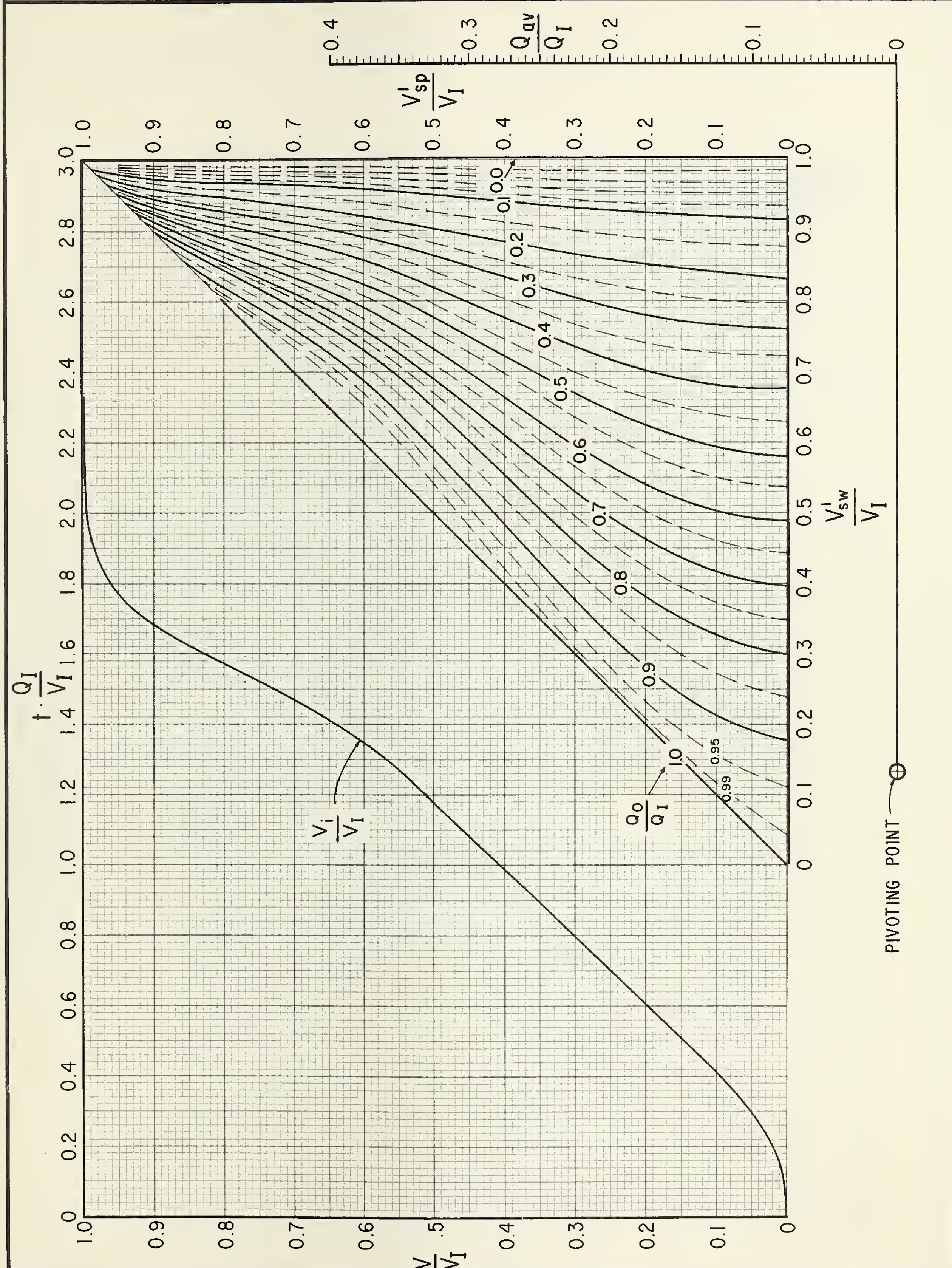


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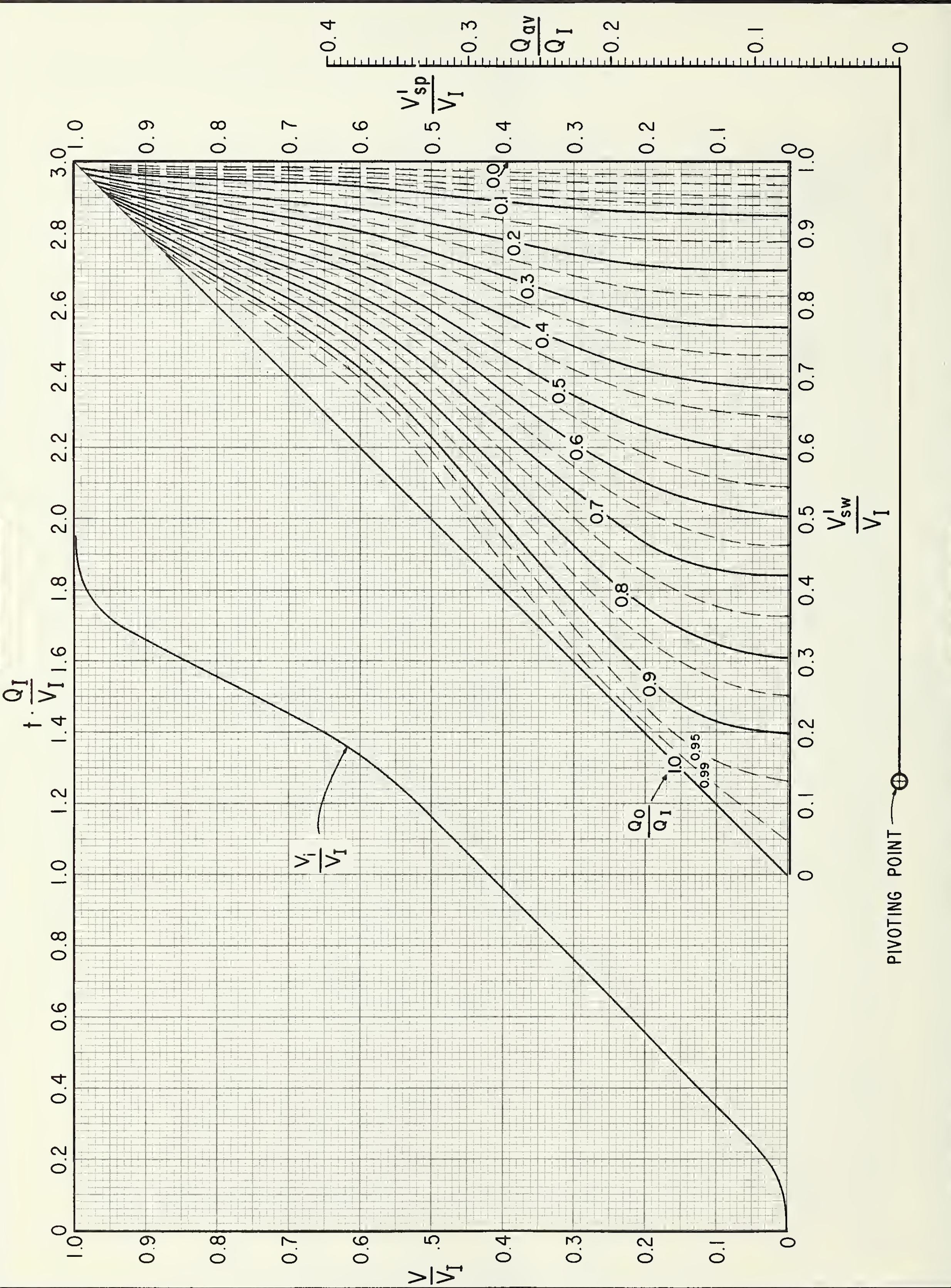
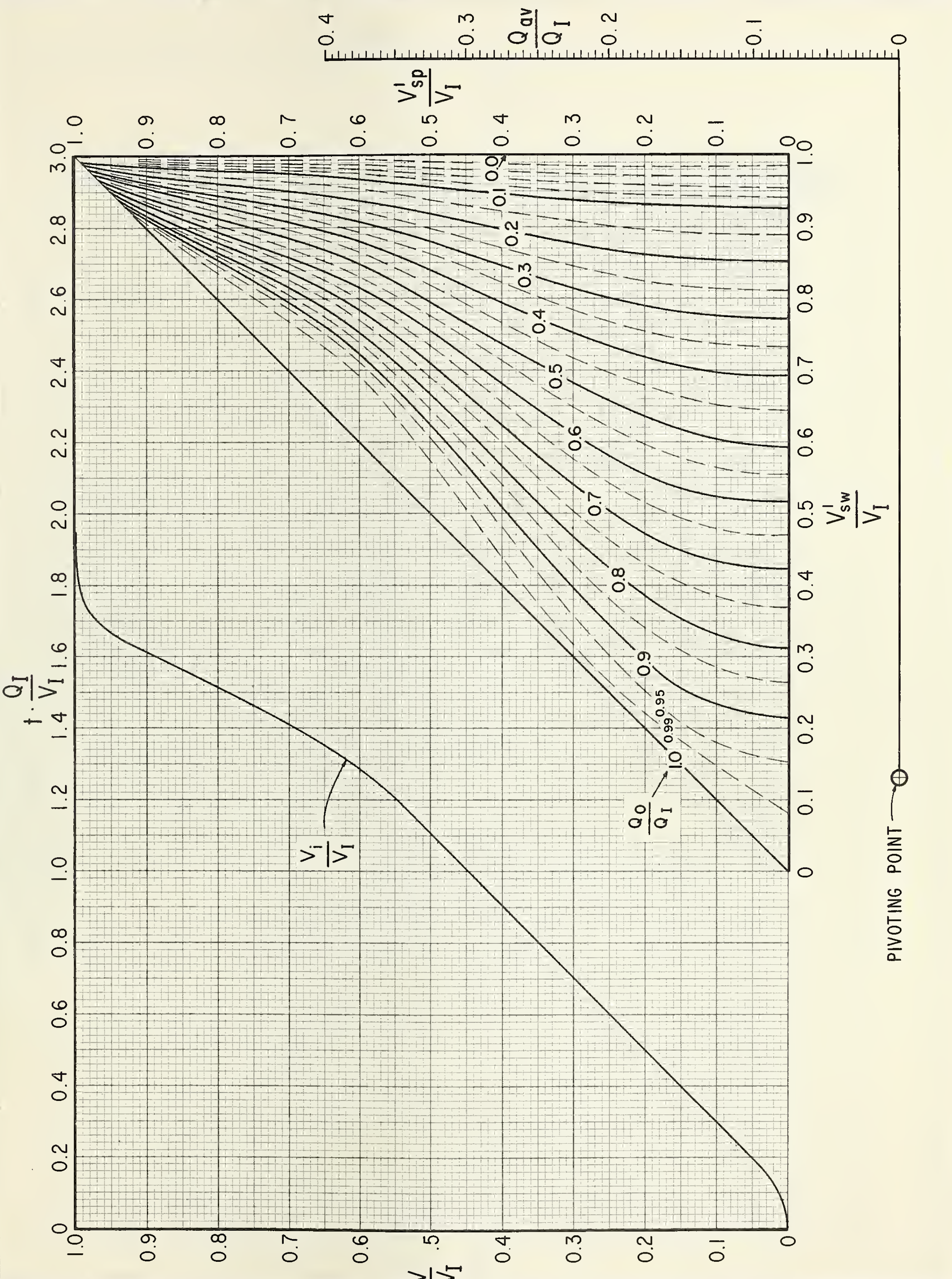
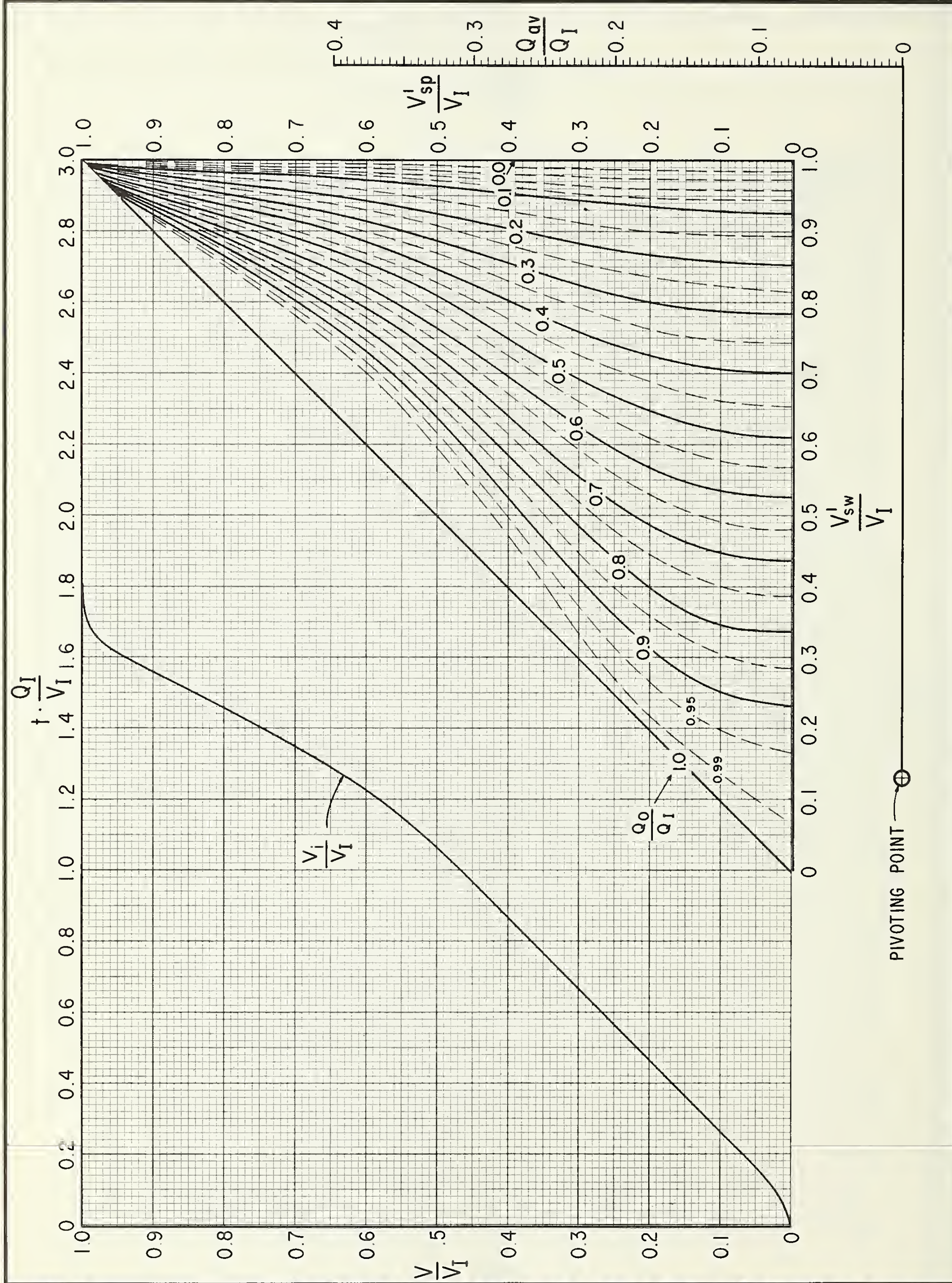
STANDARD DWG. NO.
ES-605
SHEET 7 OF 11
DATE November, 1965


$t \cdot \frac{Q_I}{V_I}$
$\frac{V}{V_I}$
$\frac{V_i}{V_I}$
$\frac{V'_{sw}}{V_I}$
$\frac{V'_{sp}}{V_I}$
$\frac{Q_{av}}{Q_I}$
$\frac{Q_o}{Q_I}$
PIVOTING POINT


$\frac{Q_{av}}{Q_I}$
0.4
0.3
0.2
0.1
0
$\frac{V'_{sp}}{V_I}$
$\frac{V'_{sw}}{V_I}$
$t \cdot \frac{Q_I}{V_I}$
$\frac{V_i}{V_I}$
$\frac{Q_o}{Q_I}$
$\frac{V}{V_I}$
PIVOTING POINT

REFERENCE

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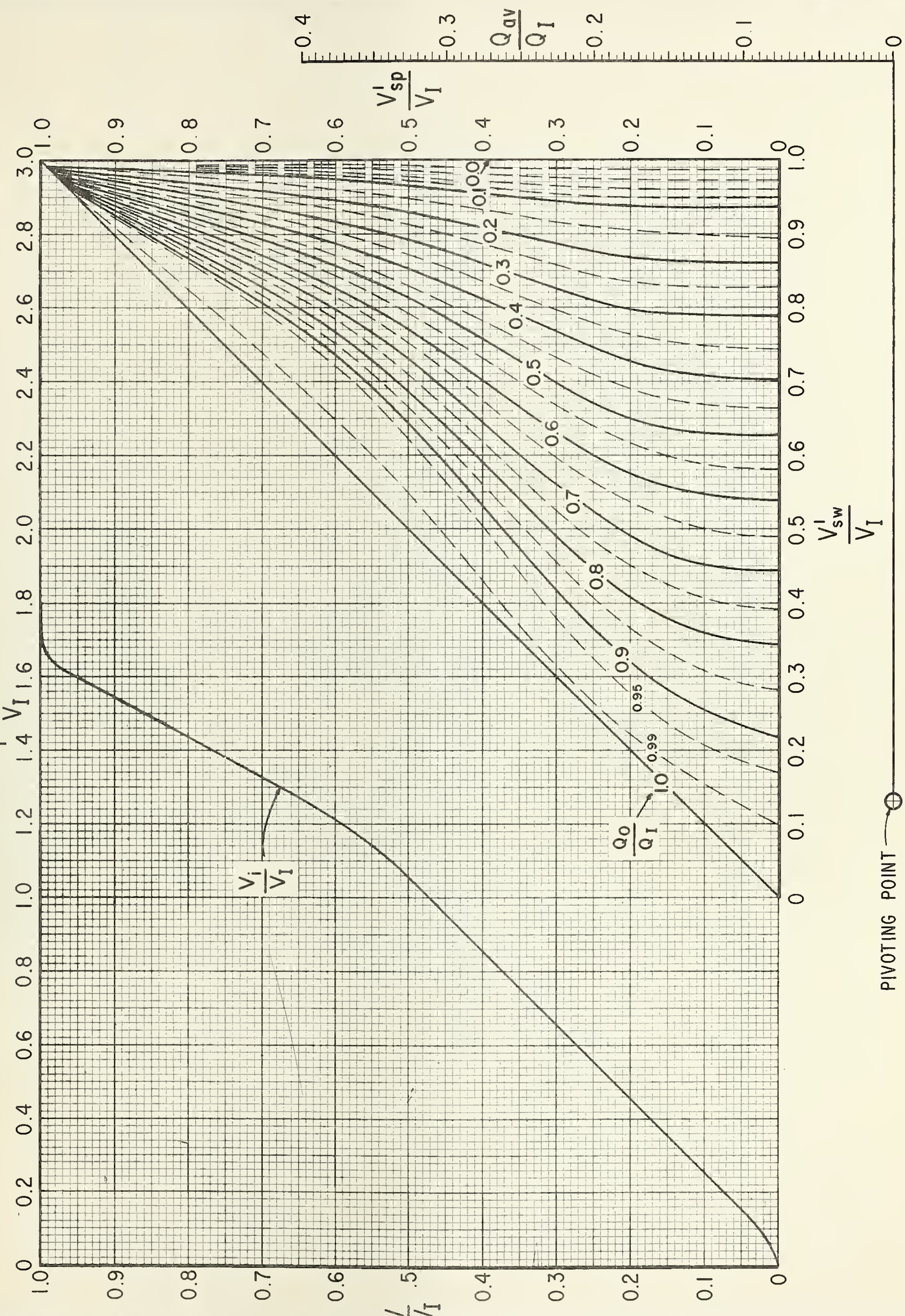
STANDARD DWG. NO.
ES-605
SHEET 10 OF 11
DATE November, 1965

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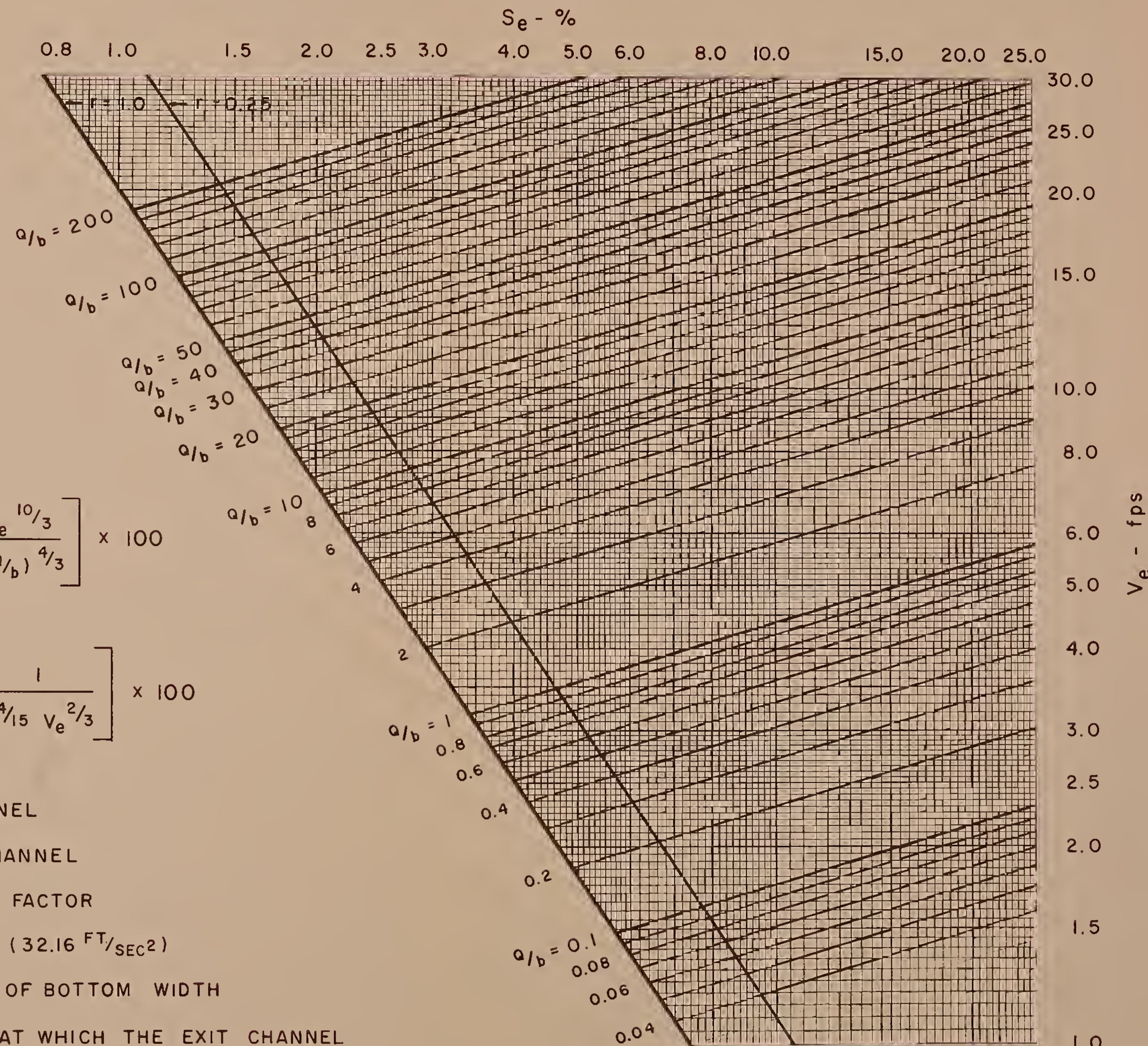
STANDARD DWG. NO.
ES-605
SHEET 11 OF 11
DATE November, 1965

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, VELOCITY CHARTS

n = 0.040




$$\% \, S_e = \left[ \frac{n^2}{1.486^2} \right] \times \left[ \frac{V_e^{10/3}}{(Q/b)^{4/3}} \right] \times 100$$

$$\% \, S_e = \left[ \frac{g^{4/3} \, n^2}{1.486^2} \right] \times \left[ \frac{1}{r^{4/15} \, V_e^{2/3}} \right] \times 100$$

$S_e$ = SLOPE OF EXIT CHANNEL

$V_e$ = VELOCITY IN EXIT CHANNEL

n = MANNING'S FRICTION FACTOR

g = GRAVITY CONSTANT (32.16 $FT/SEC^2$)

$Q/b$ = DISCHARGE PER FOOT OF BOTTOM WIDTH

r = RATIO OF DISCHARGE AT WHICH THE EXIT CHANNEL SLOPE IS EQUAL TO THE CRITICAL SLOPE.

REFERENCE

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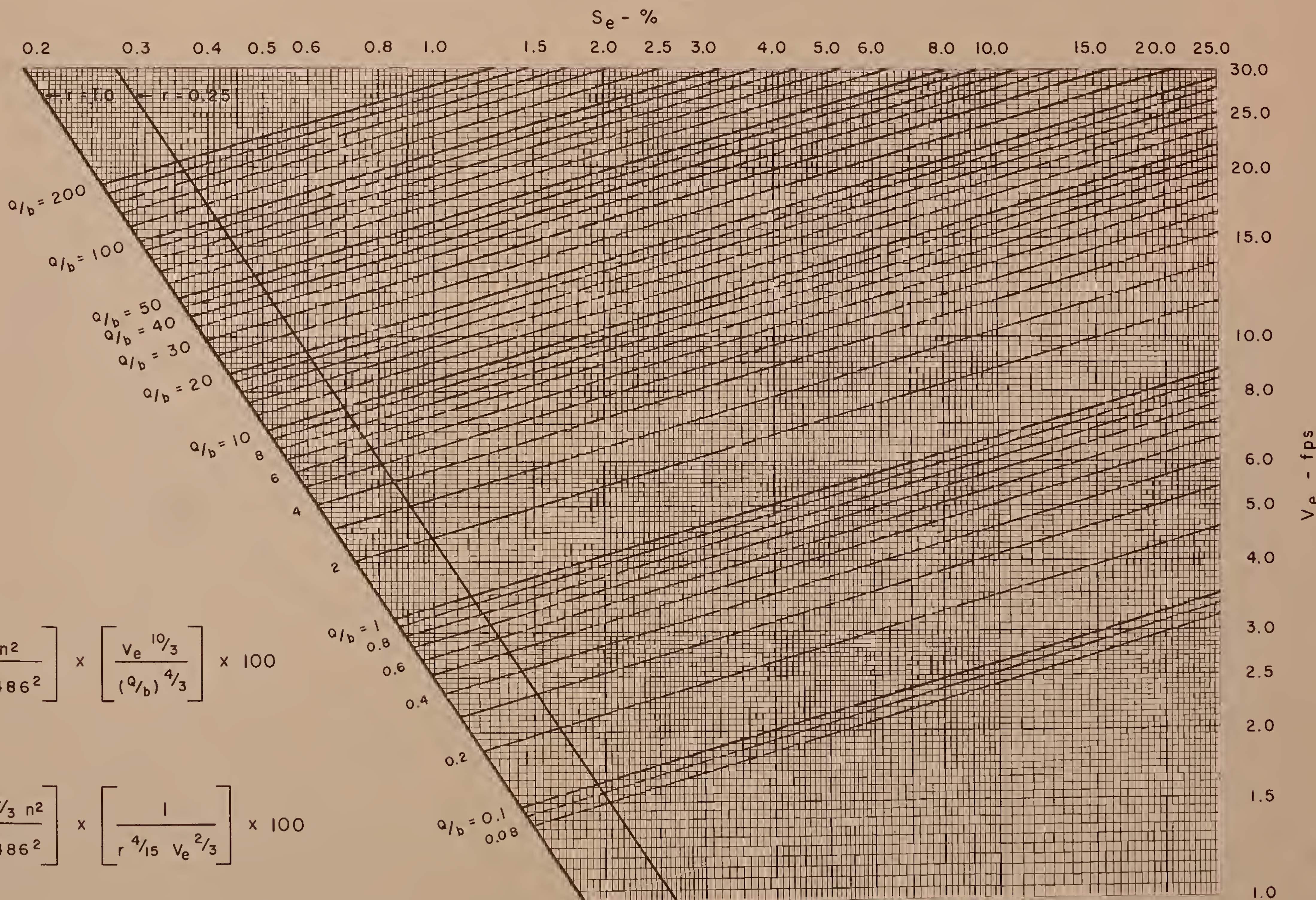
STANDARD DWG. NO.
ES-600
SHEET 1 OF 2
DATE 1-66

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, VELOCITY CHARTS

n = 0.020




$$\% S_e = \left[\frac{n^2}{1.486^2}\right] \times \left[\frac{V_e^{10/3}}{(Q/b)^{4/3}}\right] \times 100$$

$$\% S_e = \left[\frac{g^{4/3}\, n^2}{1.486^2}\right] \times \left[\frac{1}{r^{4/15}\, V_e^{2/3}}\right] \times 100$$

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STANDARD DWG. NO.
ES-600
SHEET 2 OF 2
DATE 1-66

USDA-SCS-HYATTSVILLE, MD. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

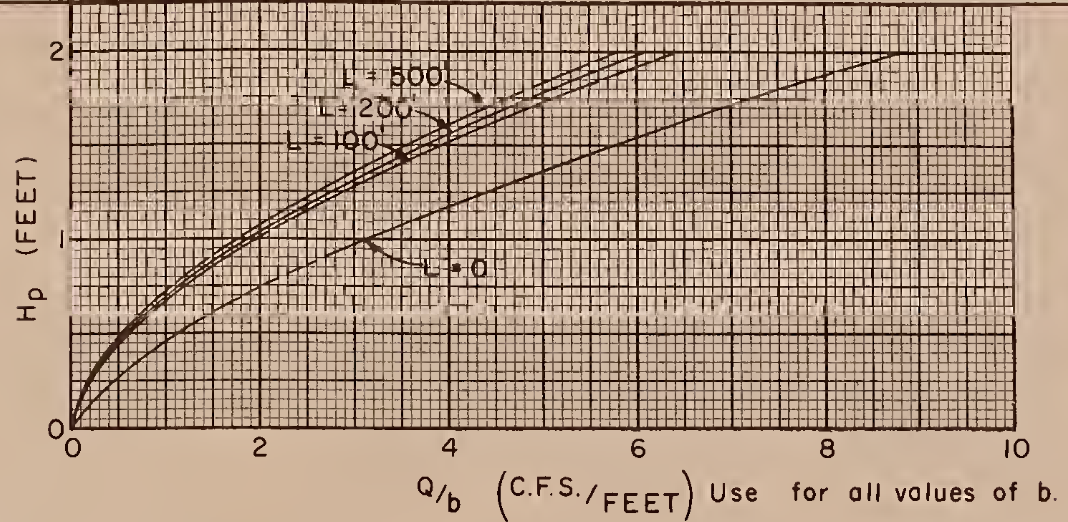
**Z = 0**

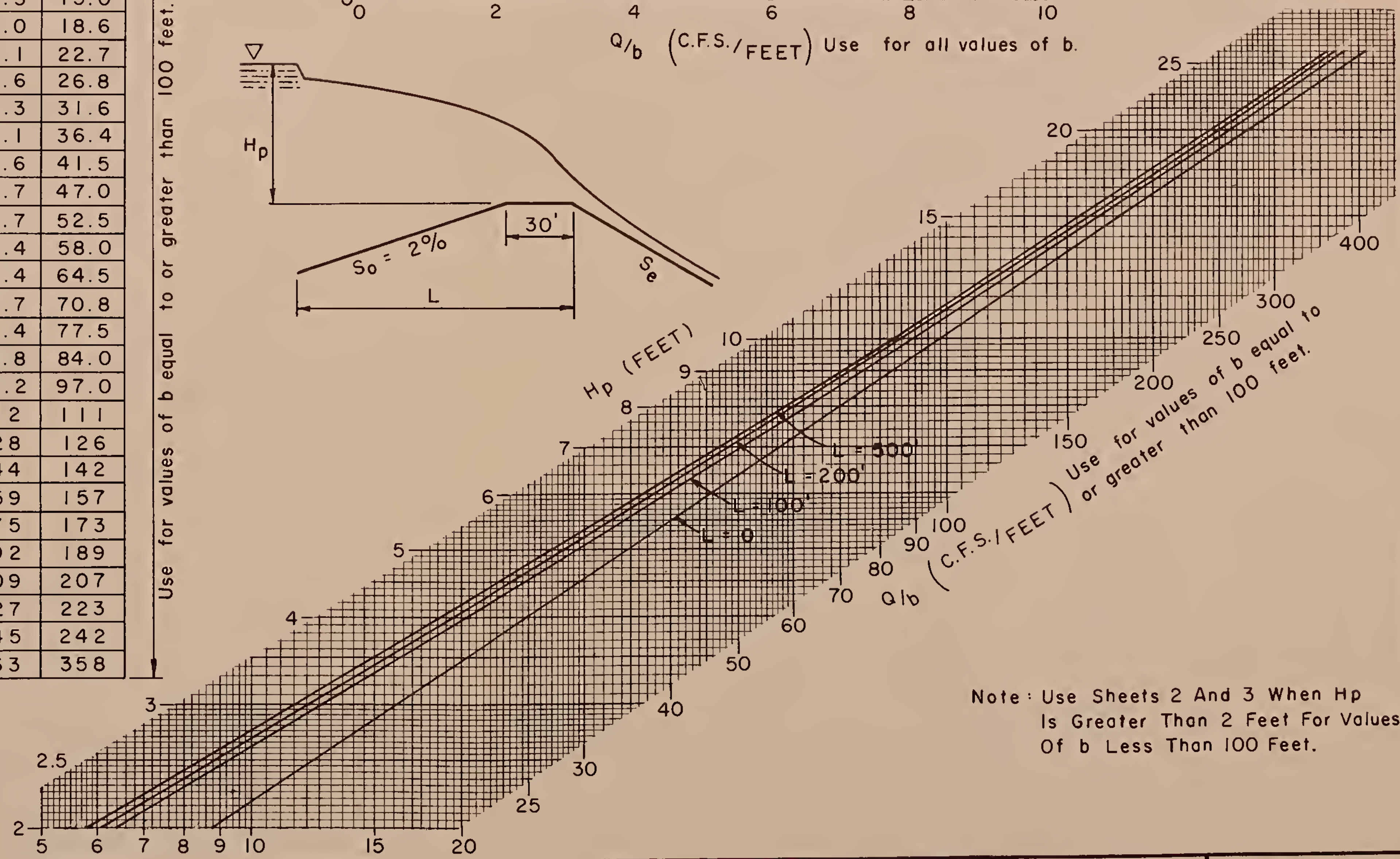
Values in Table are $Q/_b$ – C.F.S./Ft.

| Hp-Ft. \ L-Ft. | 0 | 100 | 150 | 200 | 300 | 500 |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.5 | 1.13 | 0.61 | 0.57 | 0.56 | 0.54 | 0.53 |
| 1.0 | 3.12 | 1.99 | 1.90 | 1.88 | 1.81 | 1.77 |
| 1.5 | 5.78 | 3.92 | 3.81 | 3.74 | 3.62 | 3.54 |
| 2.0 | 8.78 | 6.40 | 6.22 | 6.10 | 5.92 | 5.80 |
| 2.5 | 12.3 | 9.25 | 9.04 | 8.92 | 8.66 | 8.45 |
| 3.0 | 16.1 | 12.6 | 12.3 | 12.1 | 11.7 | 11.5 |
| 3.5 | 20.4 | 16.3 | 15.9 | 15.7 | 15.3 | 15.0 |
| 4.0 | 24.8 | 20.2 | 19.9 | 19.5 | 19.0 | 18.6 |
| 4.5 | 29.2 | 24.7 | 24.0 | 23.6 | 23.1 | 22.7 |
| 5.0 | 34.7 | 29.4 | 28.7 | 28.0 | 27.6 | 26.8 |
| 5.5 | 40.0 | 34.2 | 33.6 | 32.8 | 32.3 | 31.6 |
| 6.0 | 45.5 | 39.7 | 38.7 | 37.8 | 37.1 | 36.4 |
| 6.5 | 51.5 | 44.6 | 44.2 | 43.0 | 42.6 | 41.5 |
| 7.0 | 57.5 | 50.8 | 49.7 | 48.8 | 47.7 | 47.0 |
| 7.5 | 63.8 | 56.5 | 55.9 | 54.8 | 53.7 | 52.5 |
| 8.0 | 70.0 | 63.2 | 61.6 | 60.5 | 59.4 | 58.0 |
| 8.5 | 76.8 | 69.1 | 68.0 | 66.0 | 65.4 | 64.5 |
| 9.0 | 83.8 | 75.8 | 74.2 | 73.0 | 71.7 | 70.8 |
| 9.5 | 91.0 | 83.0 | 81.4 | 79.0 | 78.4 | 77.5 |
| 10.0 | 98.0 | 90.0 | 87.8 | 86.0 | 84.8 | 84.0 |
| 11.0 | 113 | 104 | 102 | 99.5 | 98.2 | 97.0 |
| 12.0 | 128 | 119 | 116 | 114 | 112 | 111 |
| 13.0 | 144 | 135 | 132 | 128 | 128 | 126 |
| 14.0 | 162 | 151 | 148 | 145 | 144 | 142 |
| 15.0 | 178 | 167 | 164 | 162 | 159 | 157 |
| 16.0 | 197 | 184 | 180 | 178 | 175 | 173 |
| 17.0 | 215 | 202 | 198 | 196 | 192 | 189 |
| 18.0 | 235 | 220 | 215 | 214 | 209 | 207 |
| 19.0 | 255 | 240 | 234 | 232 | 227 | 223 |
| 20.0 | 275 | 258 | 253 | 250 | 245 | 242 |
| 26.0 | 409 | 382 | 375 | 370 | 363 | 358 |

Use for all values of b. (Hp 0 – 2.0)

Use for values of b equal to or greater than 100 feet. (Hp 2.5 – 26.0)




Note: Use Sheets 2 And 3 When Hp Is Greater Than 2 Feet For Values Of b Less Than 100 Feet.

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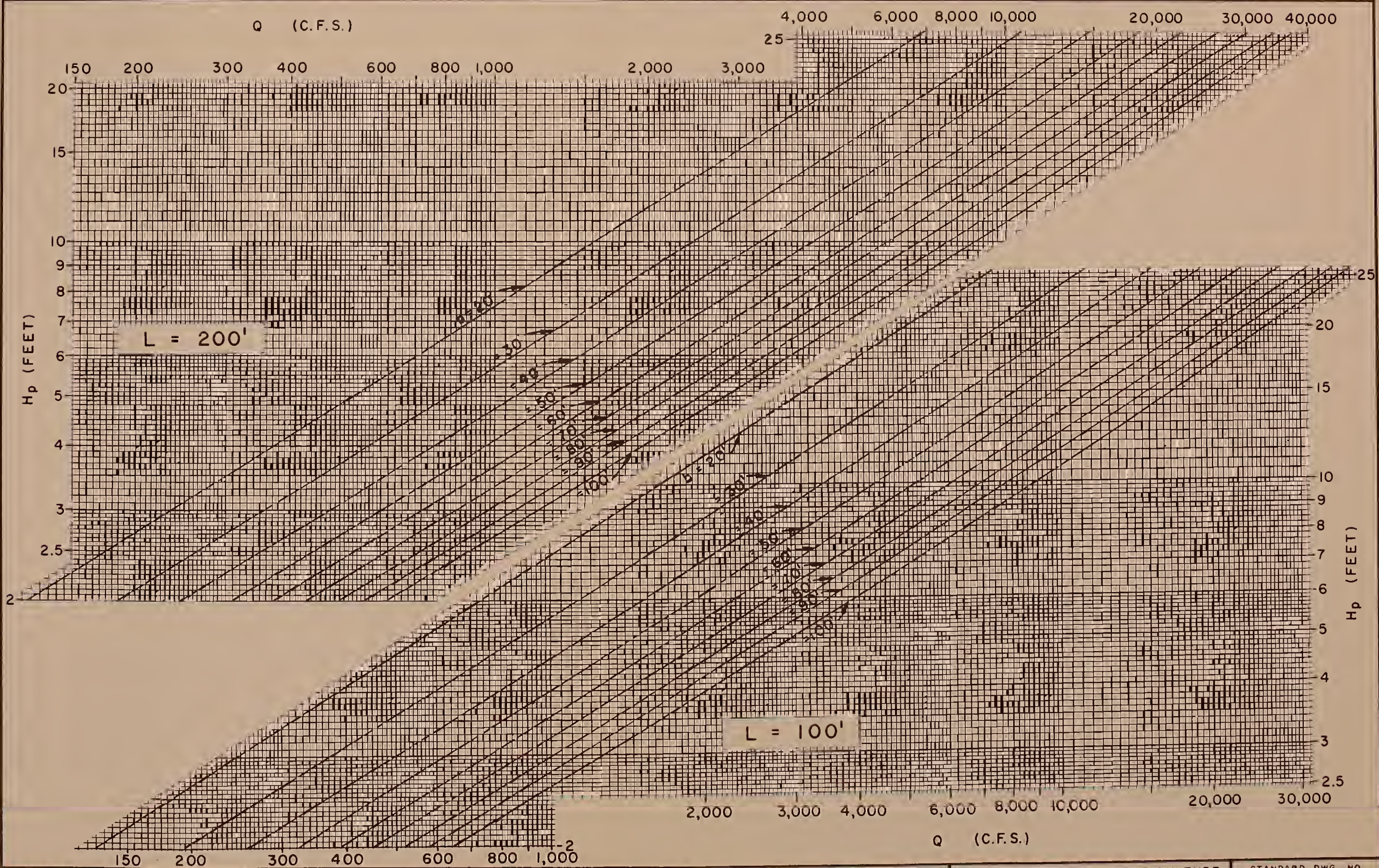
STANDARD DWG. NO. ES - 606
SHEET 1 OF 3
DATE Jan. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS DISCHARGE CHARTS

Z = 0

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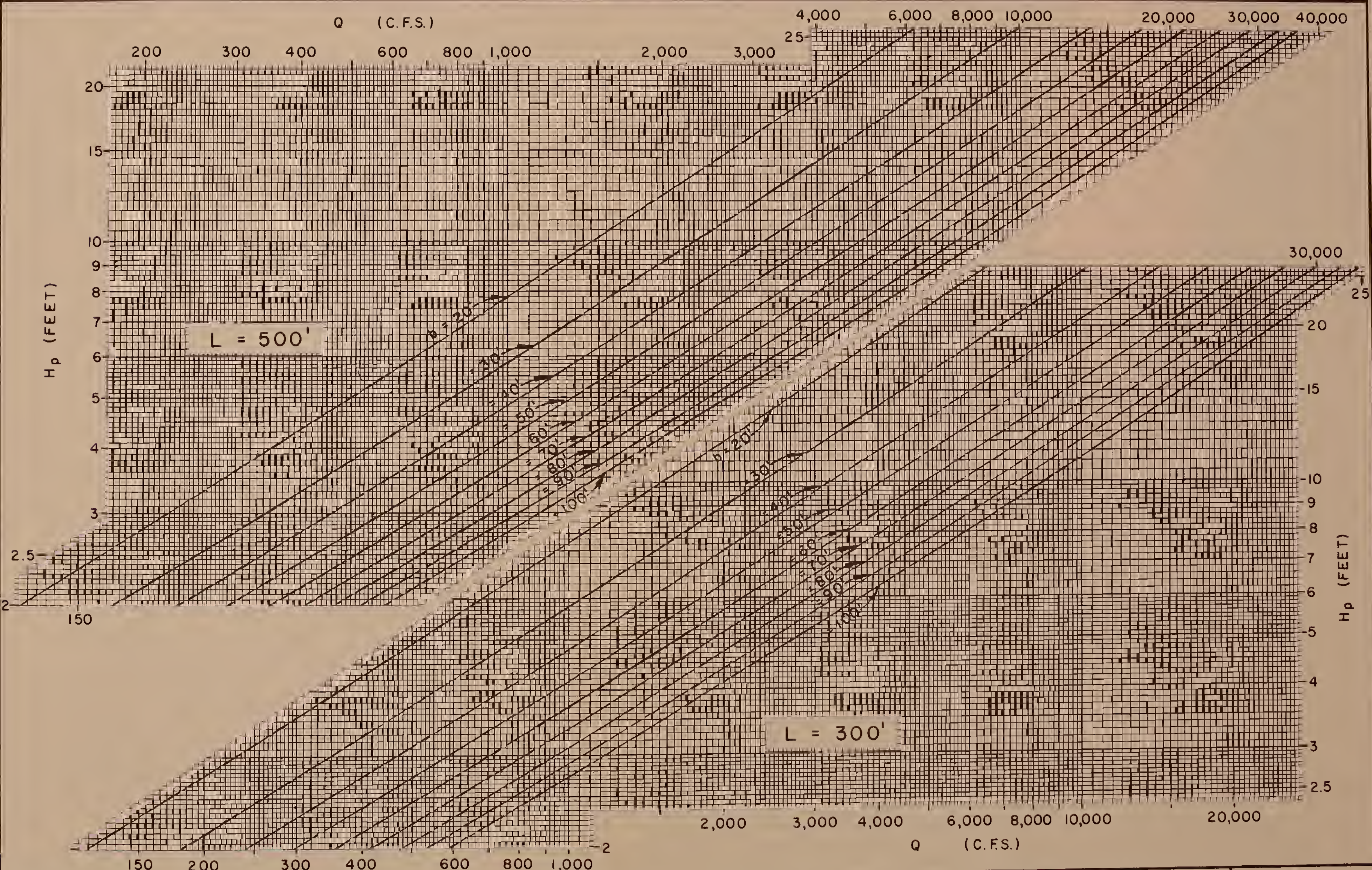
STANDARD DWG NO. ES - 606
SHEET 2 OF 3
DATE Jan. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

Z = 0

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STANDARD DWG. NO.
ES - 606
SHEET 3 OF 3
DATE Jan. 1966

USDA-SCS-HYATTSVILLE, MD. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

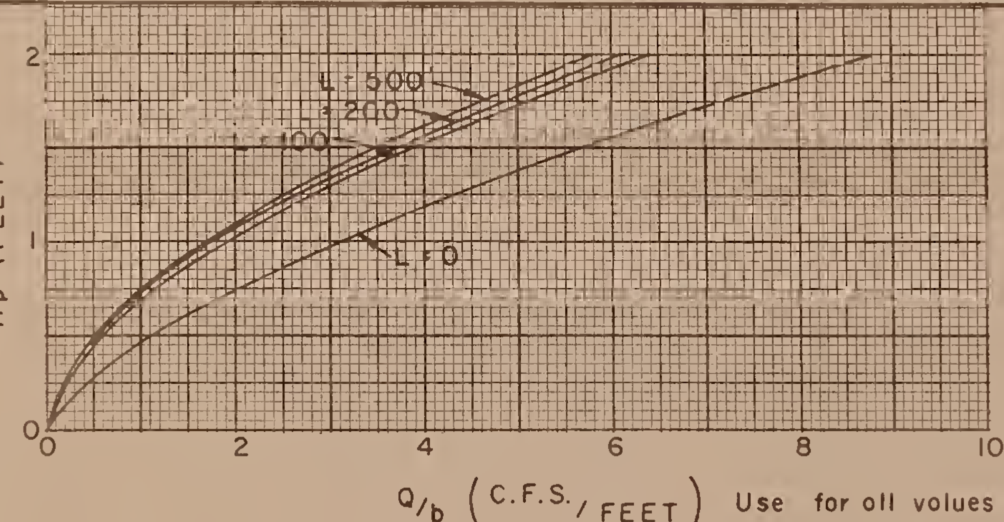
$Z = \frac{1}{2}$

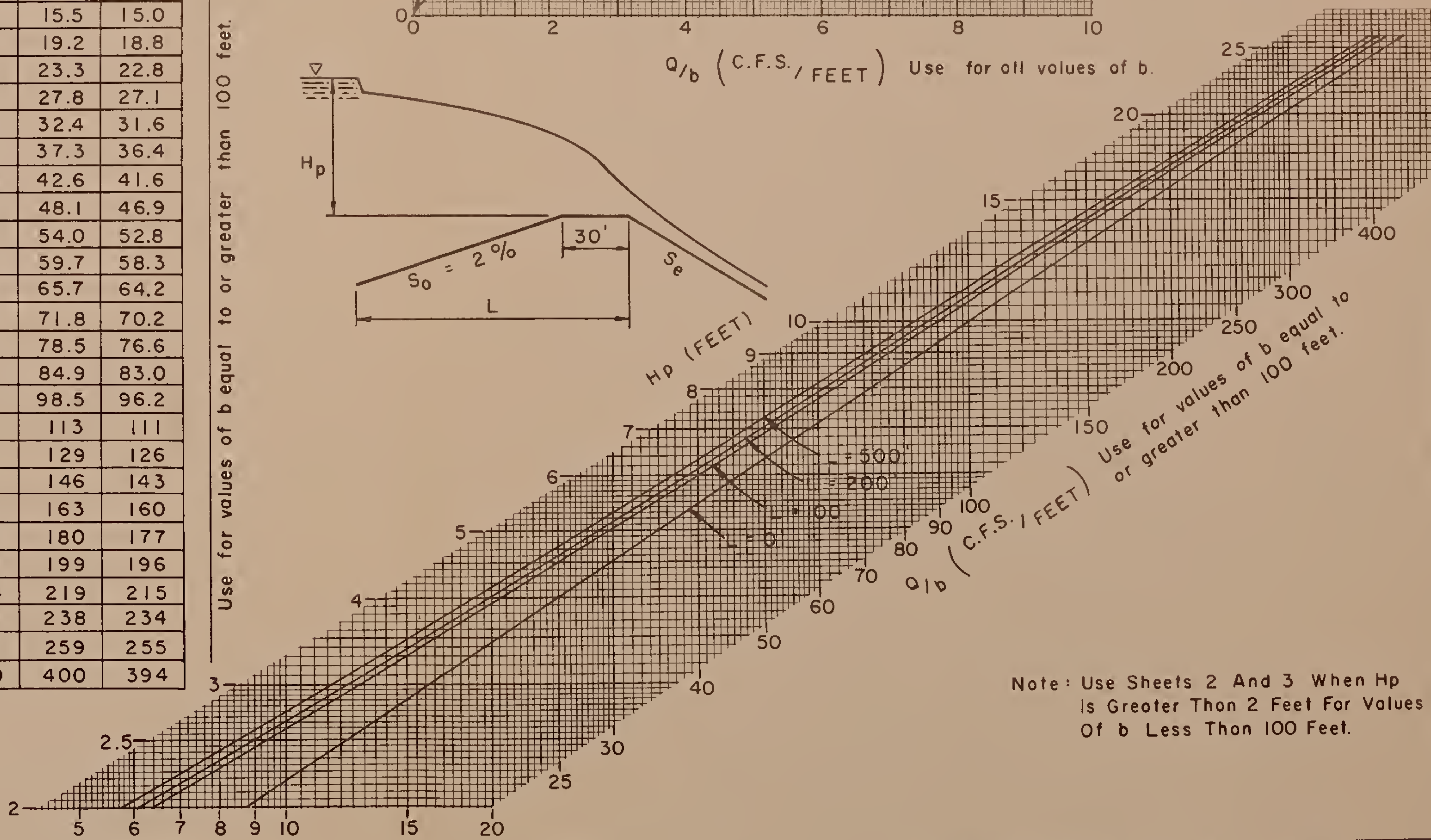
Values in Table are $Q/b$ - C.F.S./FT.

| Hp Ft. \ L-Ft. | 0 | 100 | 150 | 200 | 300 | 500 |
|---|---|---|---|---|---|---|
| 0.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.5 | 1.10 | 0.58 | 0.57 | 0.56 | 0.54 | 0.53 |
| 1.0 | 3.12 | 1.94 | 1.90 | 1.88 | 1.81 | 1.77 |
| 1.5 | 5.70 | 3.92 | 3.81 | 3.74 | 3.62 | 3.54 |
| 2.0 | 8.78 | 6.40 | 6.22 | 6.10 | 5.92 | 5.80 |
| 2.5 | 12.3 | 9.38 | 9.12 | 8.94 | 8.63 | 8.42 |
| 3.0 | 16.2 | 12.8 | 12.5 | 12.3 | 11.8 | 11.5 |
| 3.5 | 20.4 | 16.6 | 16.2 | 16.0 | 15.5 | 15.0 |
| 4.0 | 25.0 | 20.6 | 20.2 | 19.9 | 19.2 | 18.8 |
| 4.5 | 29.8 | 25.1 | 24.5 | 24.1 | 23.3 | 22.8 |
| 5.0 | 35.0 | 29.8 | 29.2 | 28.8 | 27.8 | 27.1 |
| 5.5 | 40.3 | 34.8 | 34.1 | 33.6 | 32.4 | 31.6 |
| 6.0 | 46.1 | 40.0 | 39.2 | 38.7 | 37.3 | 36.4 |
| 6.5 | 52.1 | 45.9 | 44.9 | 44.2 | 42.6 | 41.6 |
| 7.0 | 58.4 | 51.6 | 50.6 | 49.9 | 48.1 | 46.9 |
| 7.5 | 64.8 | 57.9 | 56.7 | 55.9 | 54.0 | 52.8 |
| 8.0 | 71.4 | 63.8 | 63.0 | 61.8 | 59.7 | 58.3 |
| 8.5 | 78.2 | 70.2 | 68.9 | 68.0 | 65.7 | 64.2 |
| 9.0 | 85.2 | 76.8 | 75.2 | 74.2 | 71.8 | 70.2 |
| 9.5 | 92.8 | 84.0 | 82.3 | 81.2 | 78.5 | 76.6 |
| 10.0 | 100 | 90.6 | 88.9 | 87.8 | 84.9 | 83.0 |
| 11.0 | 116 | 105 | 103 | 102 | 98.5 | 96.2 |
| 12.0 | 133 | 121 | 119 | 117 | 113 | 111 |
| 13.0 | 150 | 137 | 135 | 133 | 129 | 126 |
| 14.0 | 169 | 154 | 152 | 150 | 146 | 143 |
| 15.0 | 187 | 172 | 169 | 167 | 163 | 160 |
| 16.0 | 207 | 190 | 186 | 184 | 180 | 177 |
| 17.0 | 228 | 210 | 206 | 204 | 199 | 196 |
| 18.0 | 250 | 231 | 227 | 224 | 219 | 215 |
| 19.0 | 271 | 252 | 247 | 244 | 238 | 234 |
| 20.0 | 294 | 274 | 269 | 265 | 259 | 255 |
| 26.0 | 444 | 420 | 417 | 409 | 400 | 394 |

Use for all values of b. (Hp 0.0–2.0)

Use for values of b equal to or greater than 100 feet. (Hp 2.5–26.0)




Note: Use Sheets 2 And 3 When Hp Is Greater Than 2 Feet For Values Of b Less Than 100 Feet.

REFERENCE

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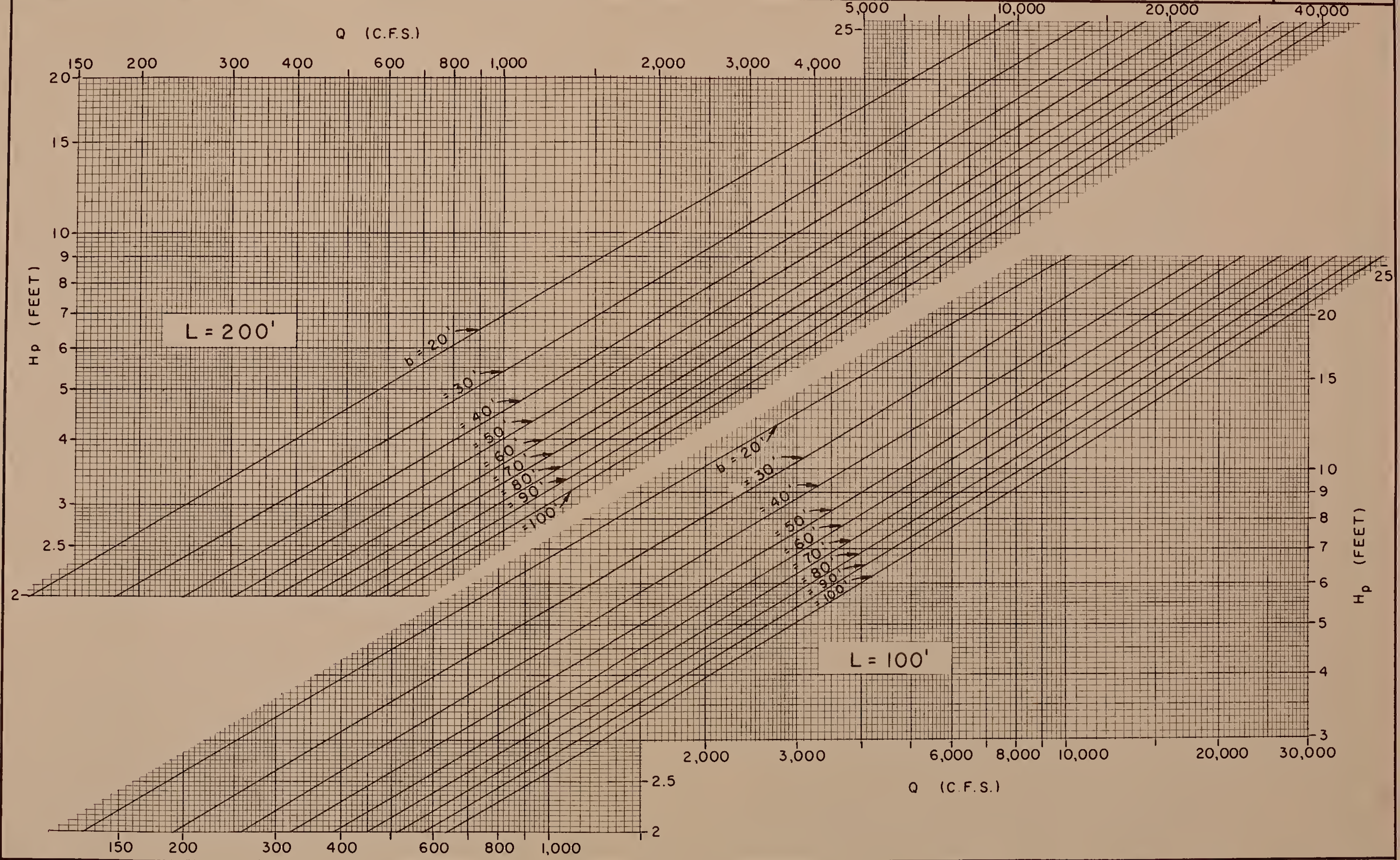
UPPER DARBY, PENNSYLVANIA

STANDARD DWG. NO. ES - 607
SHEET 1 OF 3
DATE Jan. 1966

# UD METHOD : EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

Z = ½

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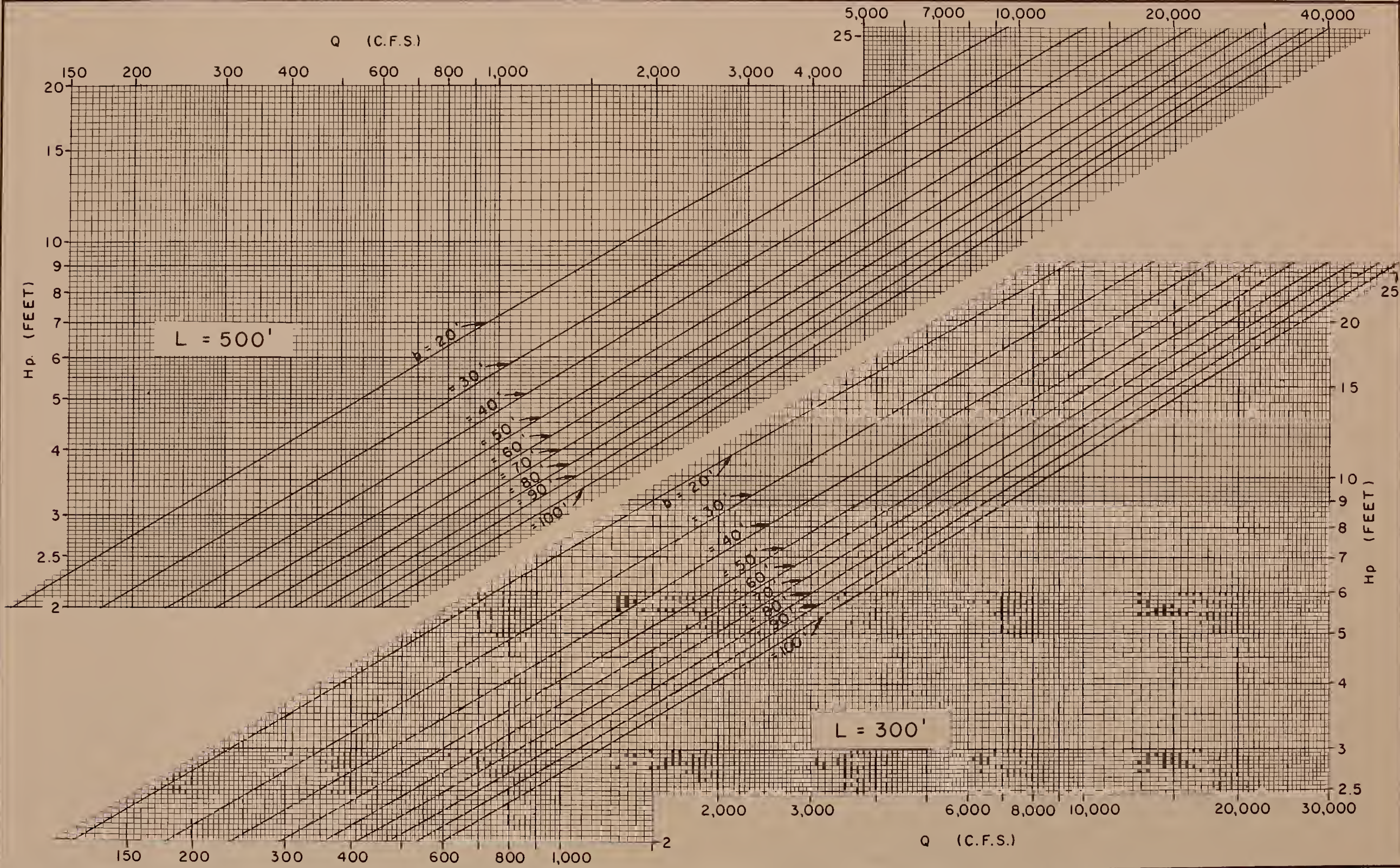
STANDARD DWG. NO.
ES - 607
SHEET 2 OF 3
DATE Jan. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

Z = ½




REFERENCE

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UPPER DARBY, PENNSYLVANIA

STANDARD DWG. NO.
ES - 607
SHEET 3 OF 3
DATE Jan. 1966

USDA-SCS-HYATTSVILLE, MD. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

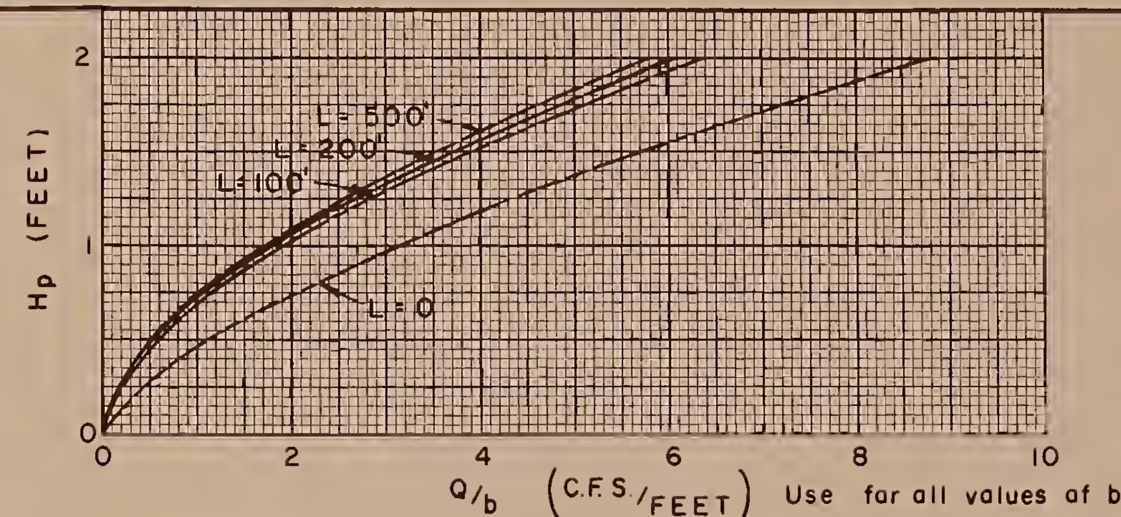
Z = 1

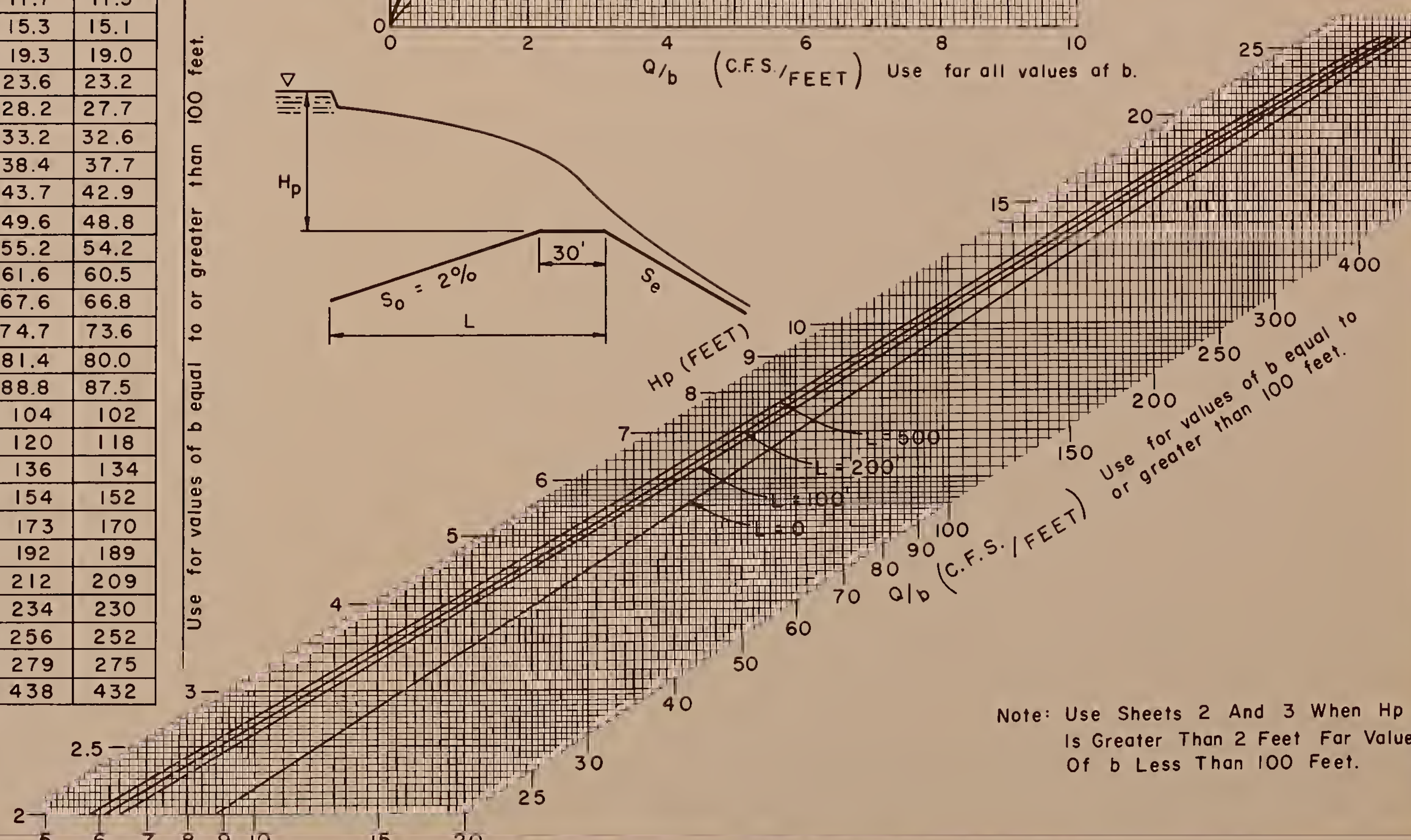
Values in Table are $Q/b$ – C.F.S./Ft.

| Hp-Ft. \ L-Ft. | 0 | 100 | 150 | 200 | 300 | 500 |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.5 | 1.10 | 0.58 | 0.57 | 0.56 | 0.54 | 0.53 |
| 1.0 | 3.12 | 1.94 | 1.90 | 1.88 | 1.81 | 1.77 |
| 1.5 | 5.70 | 3.92 | 3.81 | 3.74 | 3.62 | 3.54 |
| 2.0 | 8.78 | 6.40 | 6.22 | 6.10 | 5.92 | 5.80 |
| 2.5 | 12.5 | 9.25 | 9.01 | 8.85 | 8.61 | 8.45 |
| 3.0 | 16.4 | 12.6 | 12.3 | 12.1 | 11.7 | 11.5 |
| 3.5 | 20.8 | 16.3 | 15.9 | 15.7 | 15.3 | 15.1 |
| 4.0 | 25.4 | 20.5 | 20.1 | 19.8 | 19.3 | 19.0 |
| 4.5 | 30.4 | 25.0 | 24.5 | 24.2 | 23.6 | 23.2 |
| 5.0 | 35.8 | 30.0 | 29.4 | 29.0 | 28.2 | 27.7 |
| 5.5 | 41.3 | 35.1 | 34.4 | 34.0 | 33.2 | 32.6 |
| 6.0 | 47.1 | 40.8 | 39.9 | 39.4 | 38.4 | 37.7 |
| 6.5 | 53.1 | 46.7 | 45.7 | 45.0 | 43.7 | 42.9 |
| 7.0 | 59.7 | 52.8 | 51.7 | 50.9 | 49.6 | 48.8 |
| 7.5 | 66.0 | 59.0 | 57.7 | 56.8 | 55.2 | 54.2 |
| 8.0 | 73.3 | 66.0 | 64.3 | 63.2 | 61.6 | 60.5 |
| 8.5 | 80.2 | 72.6 | 70.9 | 69.8 | 67.6 | 66.8 |
| 9.0 | 88.0 | 80.0 | 77.8 | 76.4 | 74.7 | 73.6 |
| 9.5 | 96.0 | 87.0 | 84.9 | 83.5 | 81.4 | 80.0 |
| 10.0 | 104 | 94.2 | 92.2 | 90.8 | 88.8 | 87.5 |
| 11.0 | 120 | 110 | 103 | 106 | 104 | 102 |
| 12.0 | 138 | 127 | 124 | 122 | 120 | 118 |
| 13.0 | 156 | 144 | 141 | 139 | 136 | 134 |
| 14.0 | 176 | 162 | 159 | 157 | 154 | 152 |
| 15.0 | 197 | 182 | 179 | 177 | 173 | 170 |
| 16.0 | 218 | 201 | 198 | 196 | 192 | 189 |
| 17.0 | 240 | 223 | 219 | 217 | 212 | 209 |
| 18.0 | 264 | 245 | 241 | 239 | 234 | 230 |
| 19.0 | 288 | 268 | 265 | 262 | 256 | 252 |
| 20.0 | 313 | 292 | 288 | 285 | 279 | 275 |
| 26.0 | 480 | 458 | 452 | 448 | 438 | 432 |

Use for all values of b. (Hp 0 to 2.0)

Use for values of b equal to or greater than 100 feet. (Hp 2.5 to 26.0)




Note: Use Sheets 2 And 3 When Hp Is Greater Than 2 Feet For Values Of b Less Than 100 Feet.

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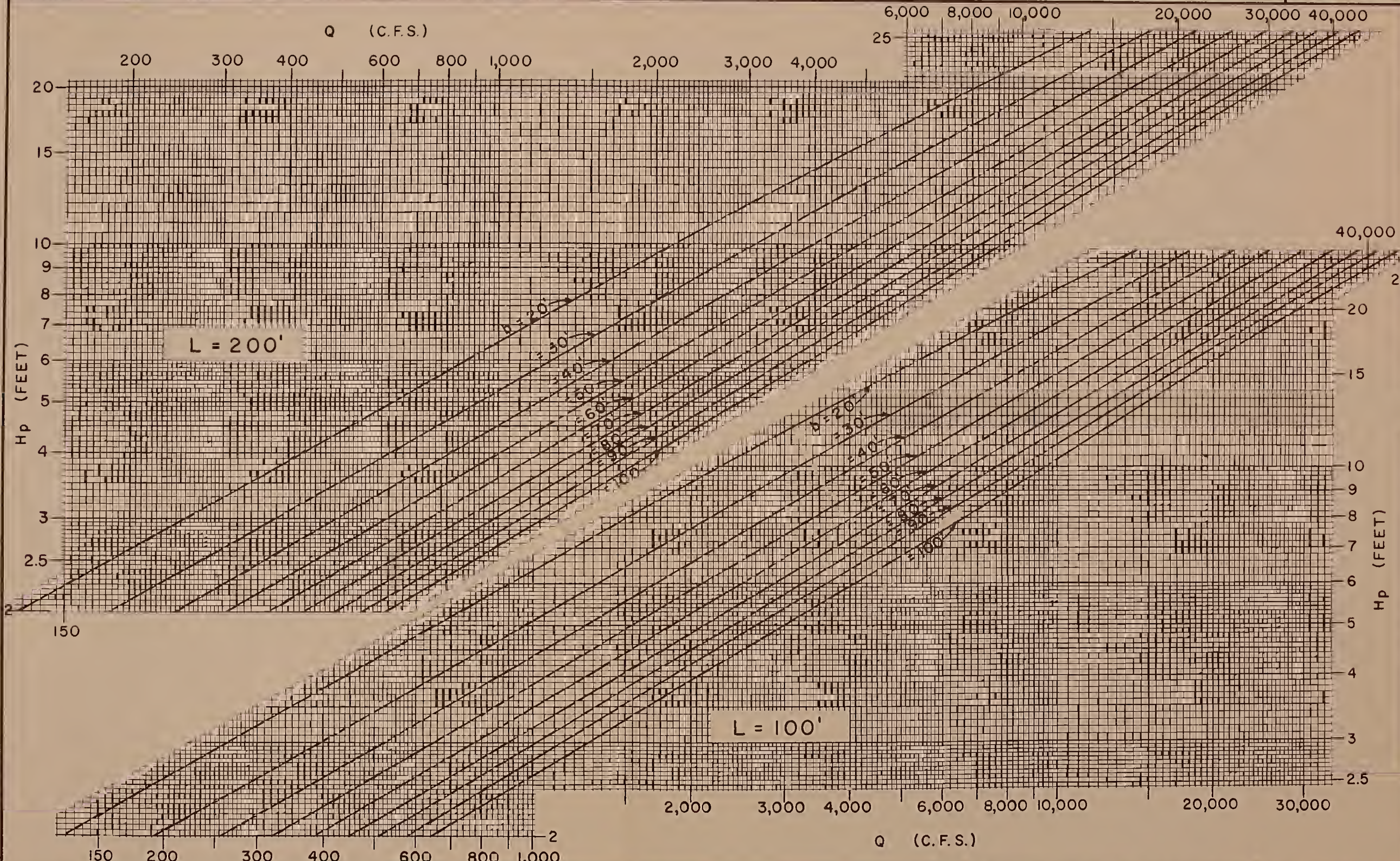
UPPER DARBY, PENNSYLVANIA

STANDARD DWG. NO.
ES - 608
SHEET 1 OF 3
DATE Jan. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

Z = 1

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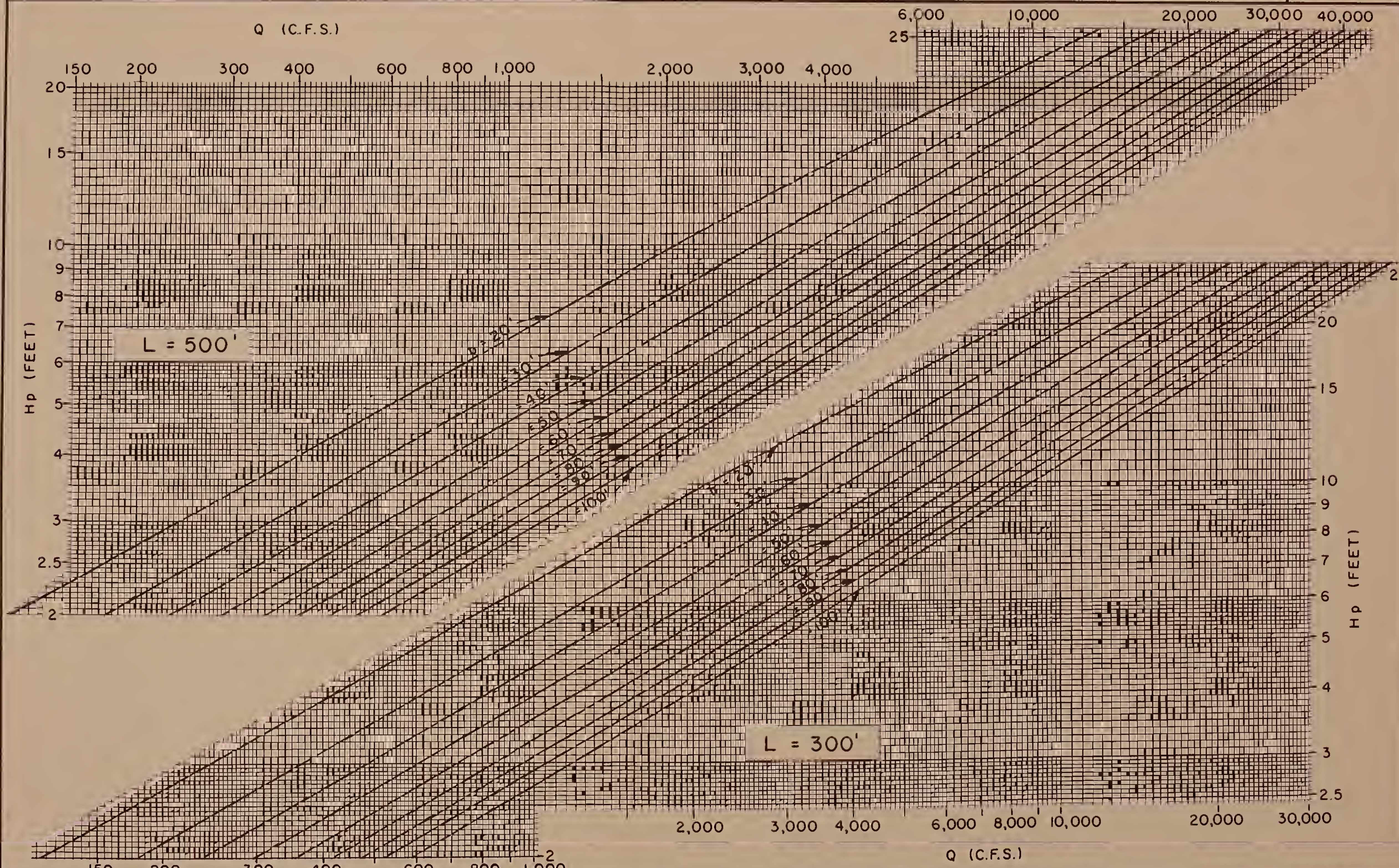
STANDARD DWG. NO.
ES - 608
SHEET 2 OF 3
DATE Jan. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

Z = 1

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STANDARD DWG. NO.
ES - 608
SHEET 3 OF 3
DATE Jan. 1966

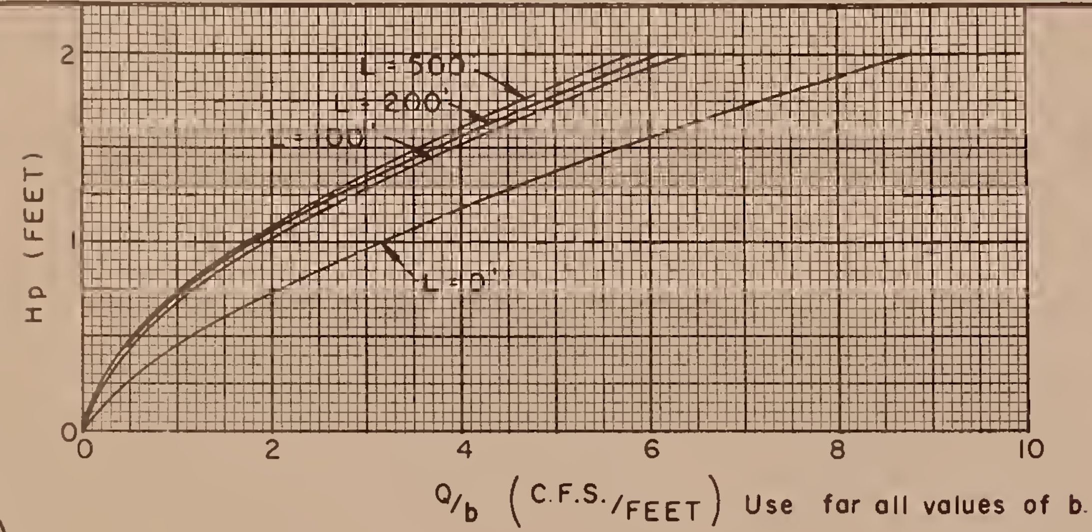
USDA-SCS-HYATTSVILLE, MD. 1966

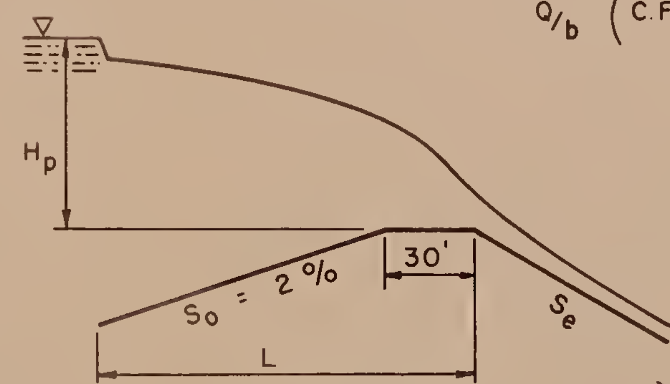
# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

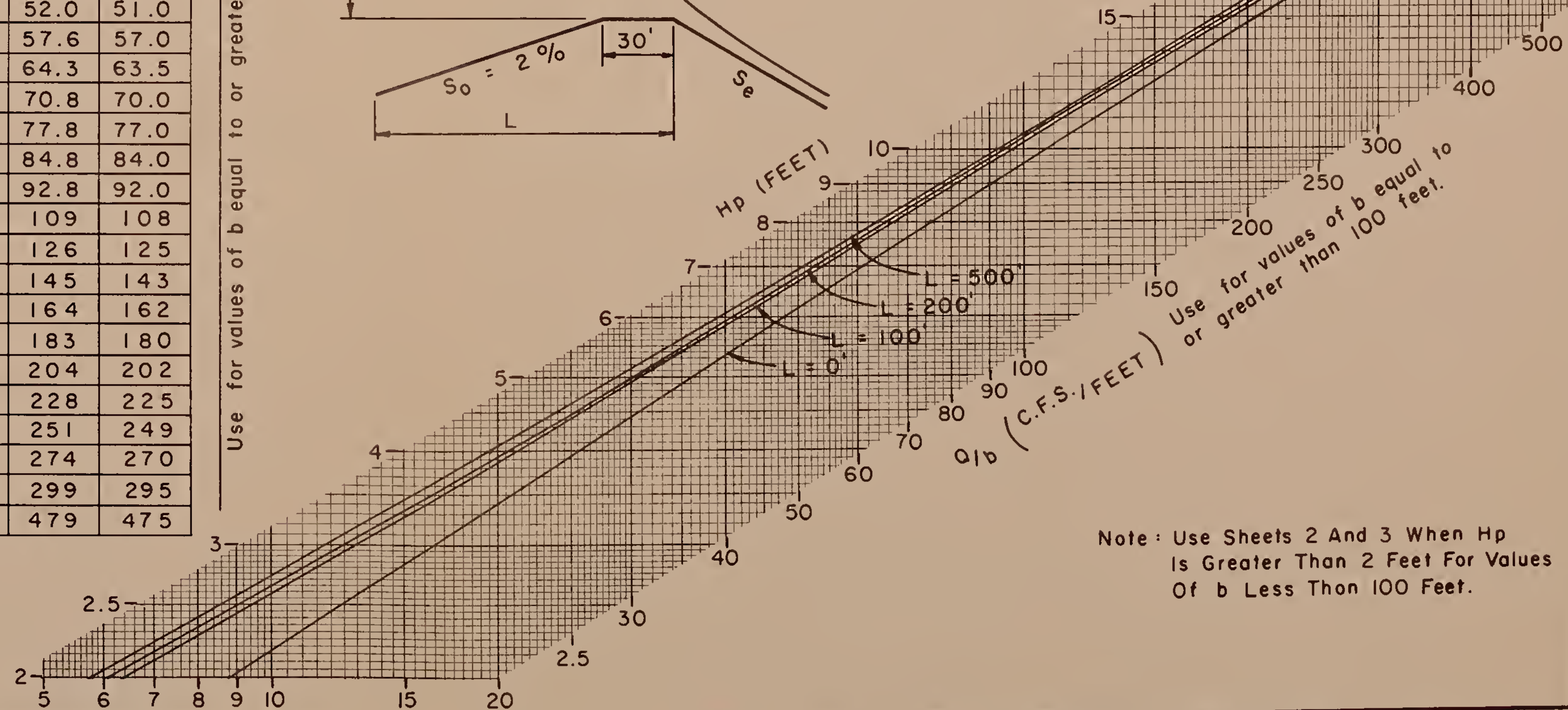
Z = 1½

Values in Table are $Q/b$ – C.F.S/FT.

| Hp-Ft. \ L-Ft. | 0 | 100 | 150 | 200 | 300 | 500 | |
|---|---|---|---|---|---|---|---|
| 0. | 0 | 0 | 0 | 0 | 0 | 0 | Use for all values of b. |
| 0.5 | 1.10 | 0.58 | 0.52 | 0.56 | 0.59 | 0.53 | |
| 1.0 | 3.12 | 1.94 | 1.90 | 1.88 | 1.81 | 1.77 | |
| 1.5 | 5.70 | 3.92 | 3.81 | 3.74 | 3.62 | 3.54 | |
| 2.0 | 8.78 | 6.40 | 6.22 | 6.10 | 5.92 | 5.80 | |
| 2.5 | 12.3 | 9.35 | 9.14 | 9.00 | 8.70 | 8.50 | Use for values of b equal to or greater than 100 feet. |
| 3.0 | 16.5 | 12.8 | 12.6 | 12.5 | 12.0 | 11.7 | |
| 3.5 | 21.0 | 16.6 | 16.4 | 16.3 | 15.8 | 15.4 | |
| 4.0 | 25.5 | 21.0 | 20.7 | 20.5 | 19.9 | 19.5 | |
| 4.5 | 31.0 | 25.7 | 25.3 | 25.0 | 24.4 | 24.0 | |
| 5.0 | 36.3 | 30.5 | 30.4 | 30.0 | 29.3 | 28.8 | |
| 5.5 | 42.0 | 36.0 | 35.4 | 35.0 | 34.1 | 33.5 | |
| 6.0 | 48.0 | 42.0 | 41.4 | 41.0 | 39.8 | 39.0 | |
| 6.5 | 54.0 | 47.5 | 46.6 | 46.0 | 45.0 | 44.4 | |
| 7.0 | 61.0 | 54.0 | 53.1 | 52.5 | 52.0 | 51.0 | |
| 7.5 | 67.5 | 60.4 | 59.3 | 58.5 | 57.6 | 57.0 | |
| 8.0 | 75.5 | 67.5 | 66.3 | 65.5 | 64.3 | 63.5 | |
| 8.5 | 82.5 | 74.0 | 72.8 | 72.0 | 70.8 | 70.0 | |
| 9.0 | 90.5 | 81.0 | 79.8 | 79.0 | 77.8 | 77.0 | |
| 9.5 | 98.0 | 88.5 | 87.0 | 86.0 | 84.8 | 84.0 | |
| 10.0 | 107 | 97.0 | 95.2 | 94.0 | 92.8 | 92.0 | |
| 11.0 | 125 | 114 | 112 | 111 | 109 | 108 | |
| 12.0 | 143 | 132 | 130 | 128 | 126 | 125 | |
| 13.0 | 164 | 151 | 149 | 148 | 145 | 143 | |
| 14.0 | 184 | 170 | 168 | 167 | 164 | 162 | |
| 15.0 | 205 | 190 | 188 | 185 | 183 | 180 | |
| 16.0 | 228 | 214 | 210 | 208 | 204 | 202 | |
| 17.0 | 253 | 235 | 233 | 232 | 228 | 225 | |
| 18.0 | 279 | 263 | 258 | 255 | 251 | 249 | |
| 19.0 | 305 | 285 | 282 | 280 | 274 | 270 | |
| 20.0 | 332 | 310 | 307 | 305 | 299 | 295 | |
| 26.0 | 525 | 490 | 487 | 485 | 479 | 475 | |




Note: Use Sheets 2 And 3 When Hp Is Greater Than 2 Feet For Values Of b Less Than 100 Feet.

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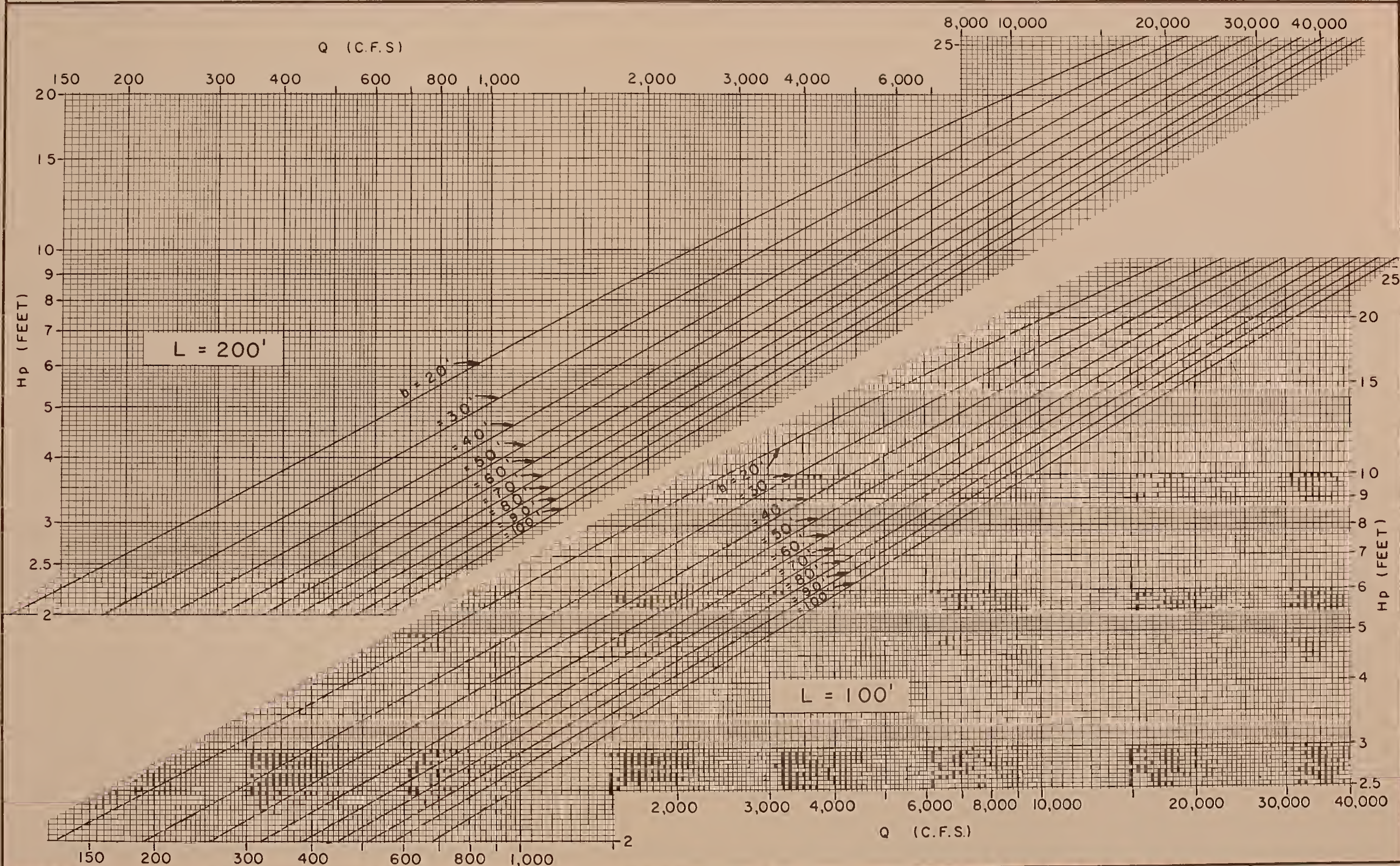
UPPER DARBY, PENNSYLVANIA

STANDARD DWG. NO. ES - 609
SHEET 1 OF 3
DATE Jan. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

Z = 1½

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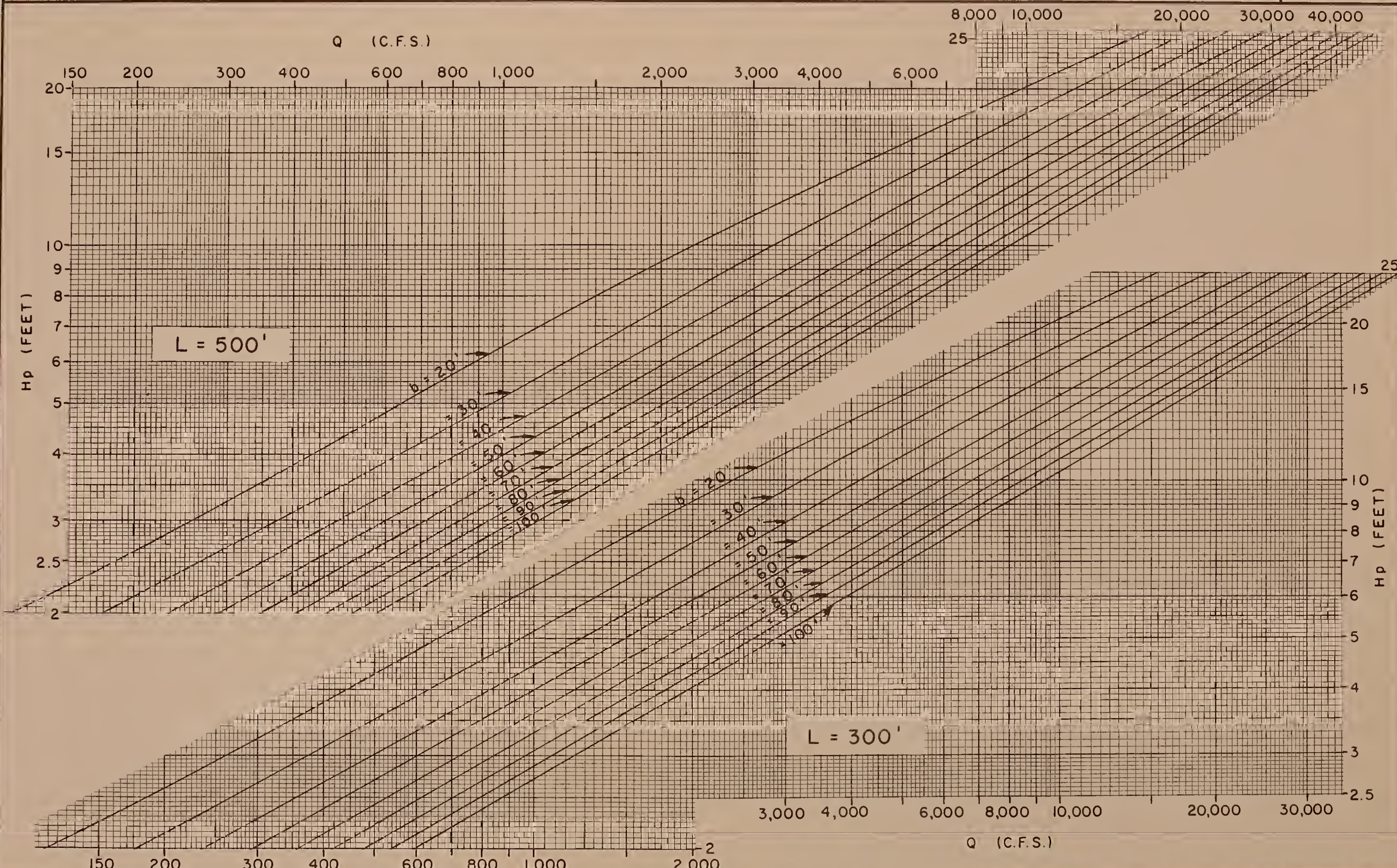
UPPER DARBY, PENNSYLVANIA

STANDARD DWG. NO.
ES - 609
SHEET 2 OF 3
DATE Jan. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

$Z = 1\frac{1}{2}$

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STANDARD DWG. NO.
ES - 609
SHEET 3 OF 3
DATE Jan. 1966

USDA-SCS-HYATTSVILLE, MD 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

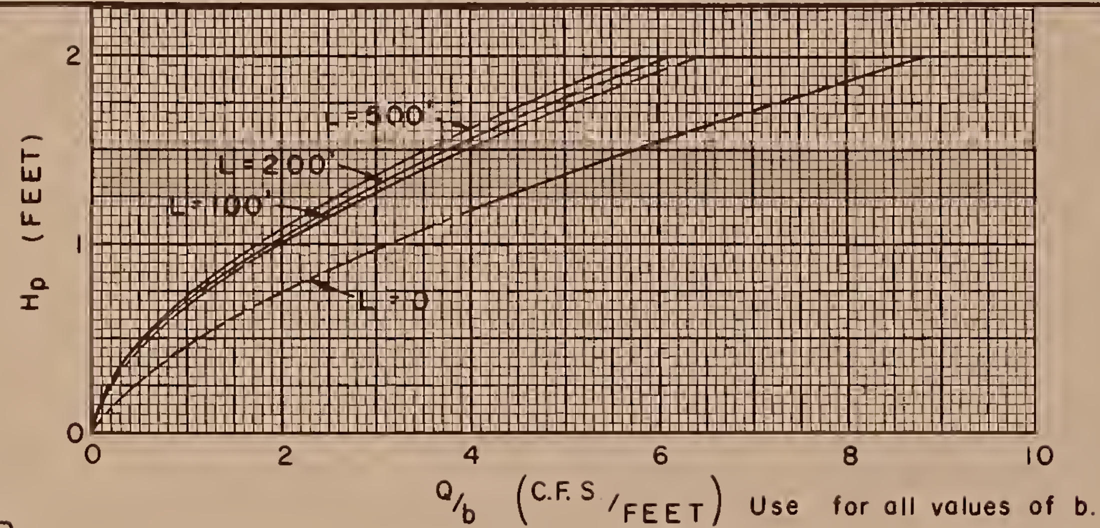
Z = 2

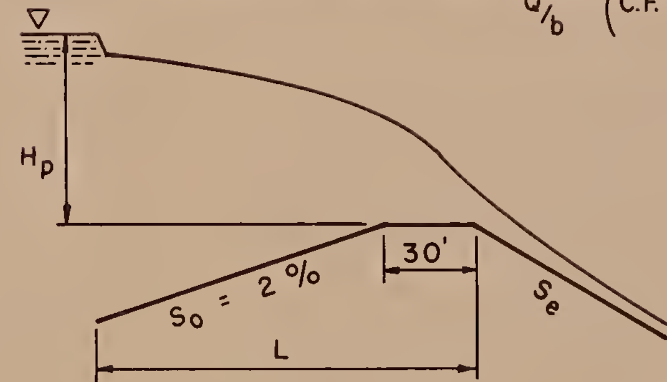
Values in Table are $Q/b$ – C.F.S./Ft.

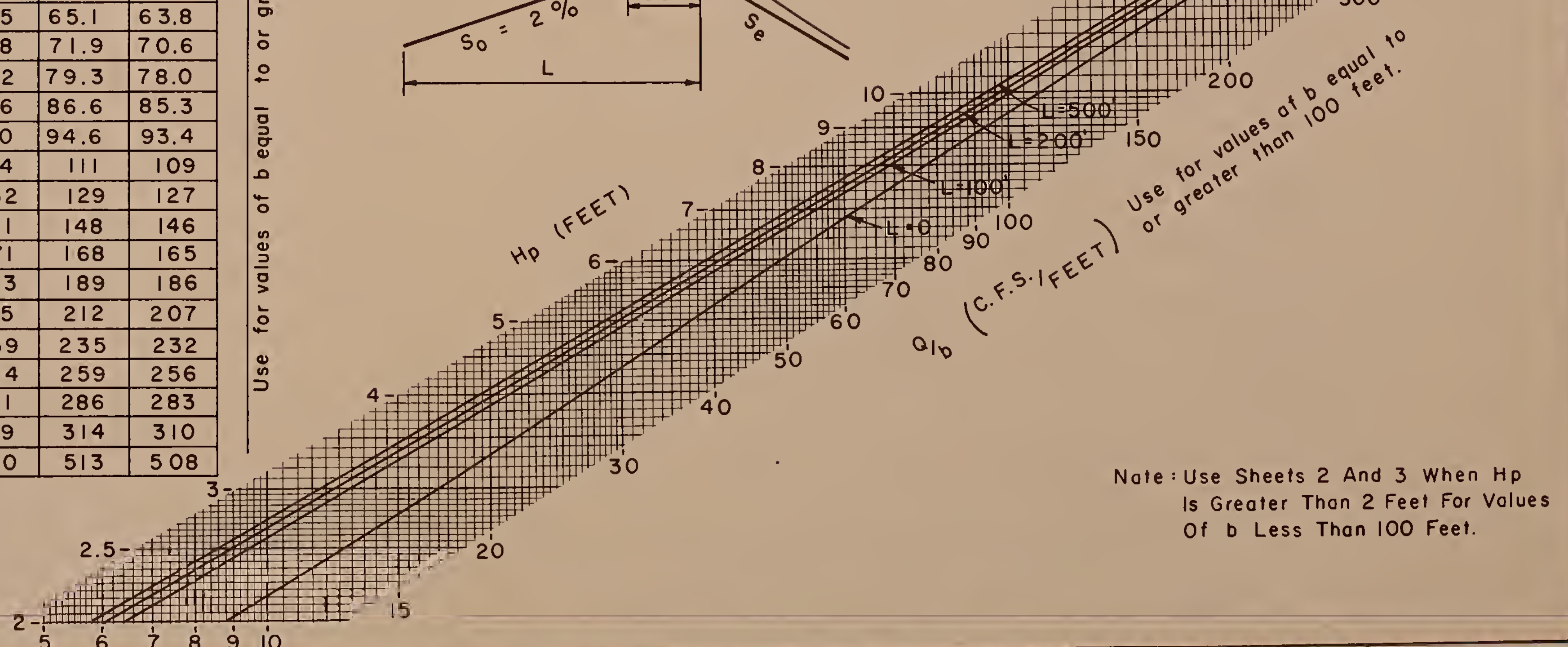
| Hp-Ft. \ L-Ft. | 0 | 100 | 150 | 200 | 300 | 500 |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.5 | 1.10 | 0.58 | 0.57 | 0.56 | 0.54 | 0.53 |
| 1.0 | 3.12 | 1.94 | 1.90 | 1.88 | 1.81 | 1.77 |
| 1.5 | 5.70 | 3.92 | 3.81 | 3.74 | 3.62 | 3.54 |
| 2.0 | 8.78 | 6.40 | 6.22 | 6.10 | 5.92 | 5.80 |
| 2.5 | 12.7 | 9.40 | 9.16 | 9.00 | 8.73 | 8.8 |
| 3.0 | 16.8 | 12.9 | 12.6 | 12.3 | 12.0 | 11.7 |
| 3.5 | 21.6 | 16.9 | 16.4 | 16.2 | 15.7 | 15.5 |
| 4.0 | 26.1 | 21.2 | 20.5 | 20.3 | 19.7 | 19.4 |
| 4.5 | 30.8 | 25.8 | 25.4 | 25.0 | 24.3 | 23.9 |
| 5.0 | 37.2 | 30.5 | 30.2 | 29.5 | 29.1 | 28.5 |
| 5.5 | 43.1 | 36.4 | 35.6 | 35.0 | 34.3 | 33.5 |
| 6.0 | 49.3 | 42.2 | 41.3 | 40.7 | 39.7 | 39.0 |
| 6.5 | 56.0 | 48.2 | 47.6 | 46.5 | 45.7 | 44.5 |
| 7.0 | 63.0 | 55.0 | 53.8 | 53.0 | 51.9 | 50.8 |
| 7.5 | 70.0 | 61.8 | 60.5 | 59.6 | 58.2 | 57.0 |
| 8.0 | 77.8 | 69.0 | 67.7 | 66.5 | 65.1 | 63.8 |
| 8.5 | 85.8 | 76.4 | 74.8 | 73.8 | 71.9 | 70.6 |
| 9.0 | 93.8 | 84.5 | 82.5 | 81.2 | 79.3 | 78.0 |
| 9.5 | 102 | 92.4 | 90.2 | 88.6 | 86.6 | 85.3 |
| 10.0 | 111 | 101 | 98.2 | 97.0 | 94.6 | 93.4 |
| 11.0 | 130 | 118 | 115 | 114 | 111 | 109 |
| 12.0 | 149 | 137 | 133 | 132 | 129 | 127 |
| 13.0 | 170 | 156 | 153 | 151 | 148 | 146 |
| 14.0 | 192 | 177 | 173 | 171 | 168 | 165 |
| 15.0 | 215 | 200 | 196 | 193 | 189 | 186 |
| 16.0 | 239 | 223 | 219 | 215 | 212 | 207 |
| 17.0 | 264 | 247 | 242 | 239 | 235 | 232 |
| 18.0 | 290 | 273 | 268 | 264 | 259 | 256 |
| 19.0 | 318 | 300 | 295 | 291 | 286 | 283 |
| 20.0 | 348 | 329 | 324 | 319 | 314 | 310 |
| 26.0 | 554 | 532 | 525 | 520 | 513 | 508 |

Use for all values of b. (Hp 0 to 2.0)

Use for values of b equal to or greater than 100 feet. (Hp 2.5 to 26.0)




Note: Use Sheets 2 And 3 When Hp Is Greater Than 2 Feet For Values Of b Less Than 100 Feet.

REFERENCE

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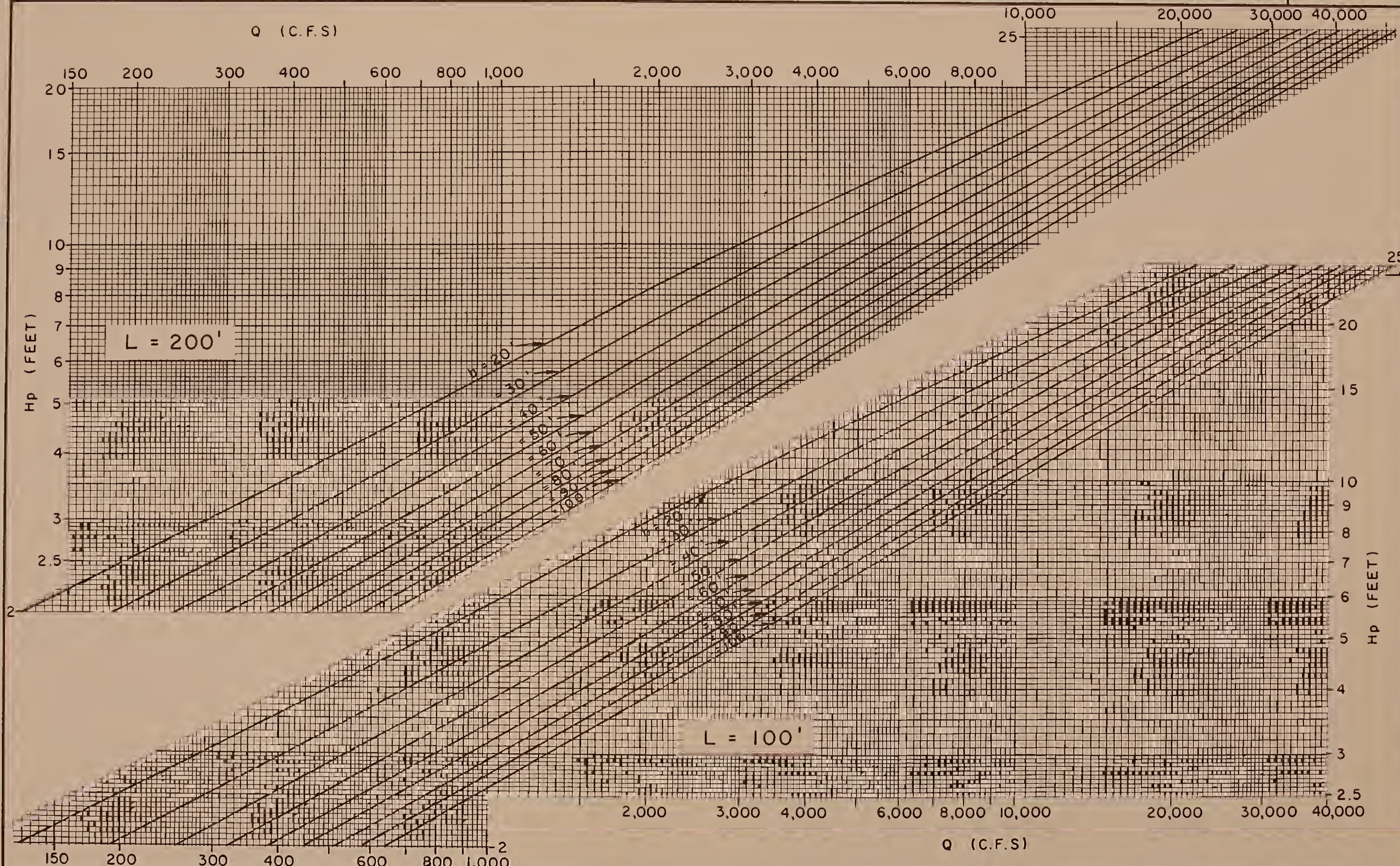
UPPER DARBY, PENNSYLVANIA

STANDARD DWG. NO.
ES - 610
SHEET 1 OF 3
DATE Jan. 1966

UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

Z = 2

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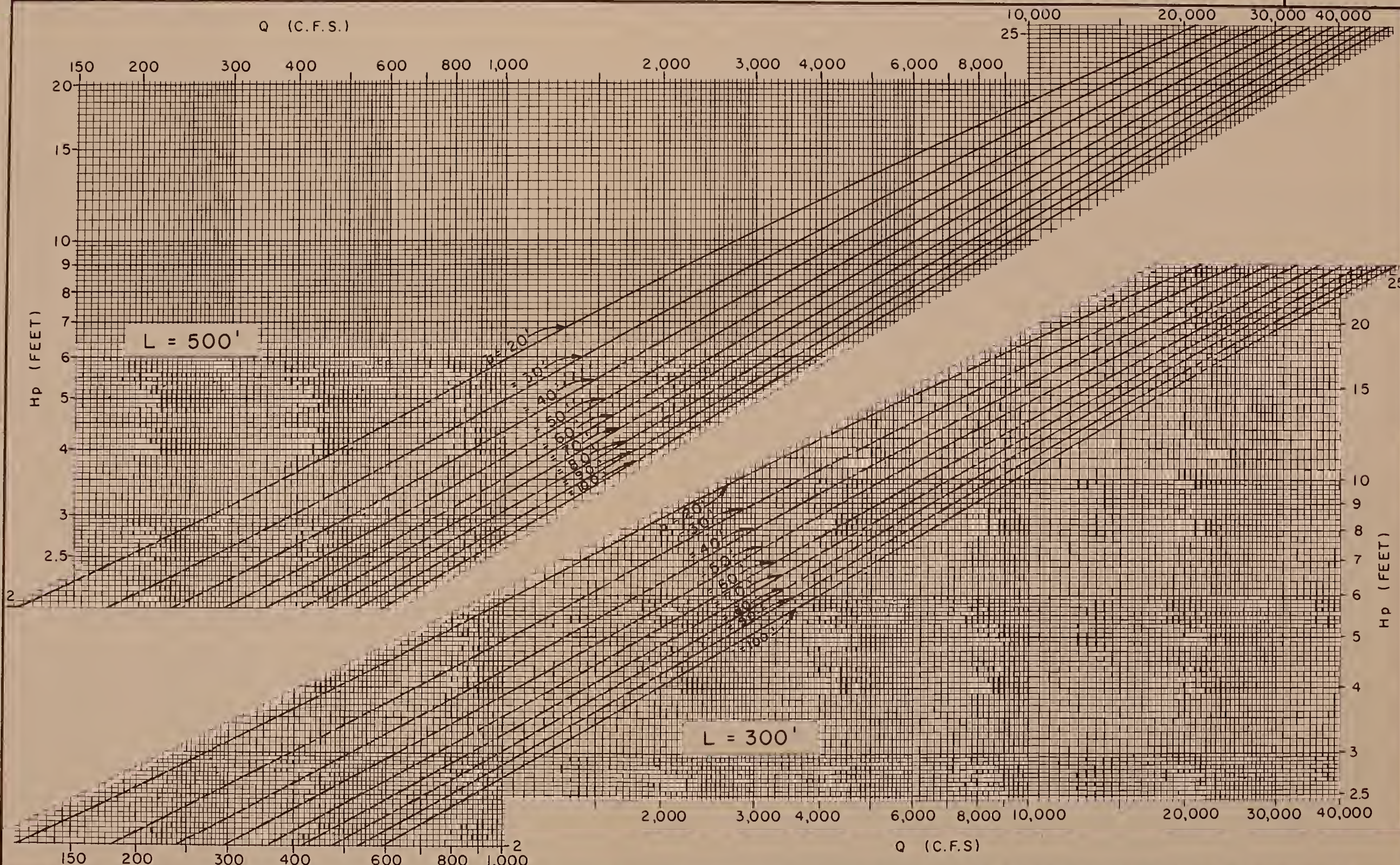
STANDARD DWG. NO.
ES - 610
SHEET 2 OF 3
DATE Jan. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

Z = 2

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STANDARD DWG. NO
ES - 610
SHEET 3 OF 3
DATE Jan. 1966

USDA-SCS-HYATTSVILLE, MD. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

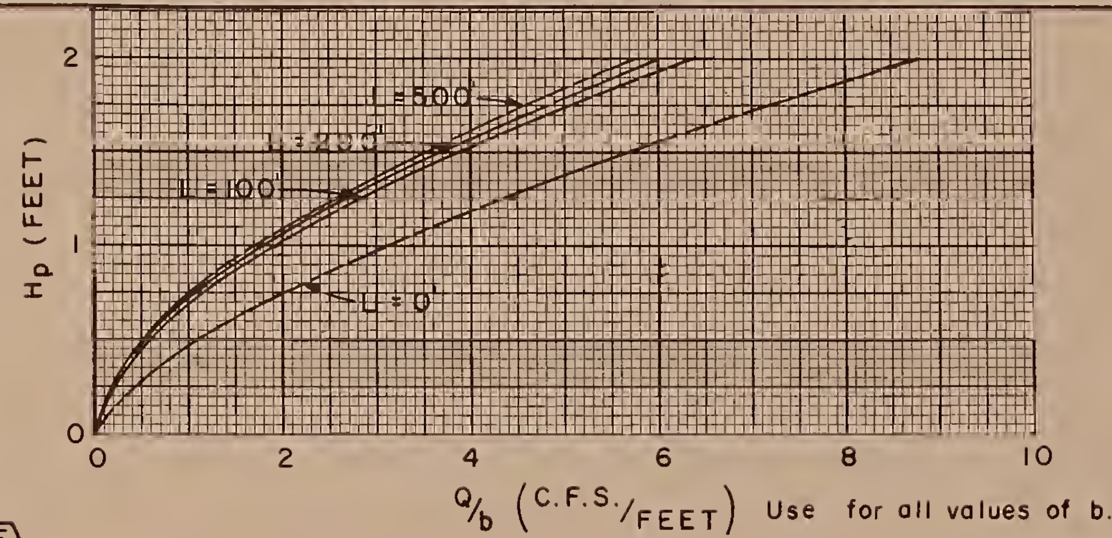
Z = 2 ½

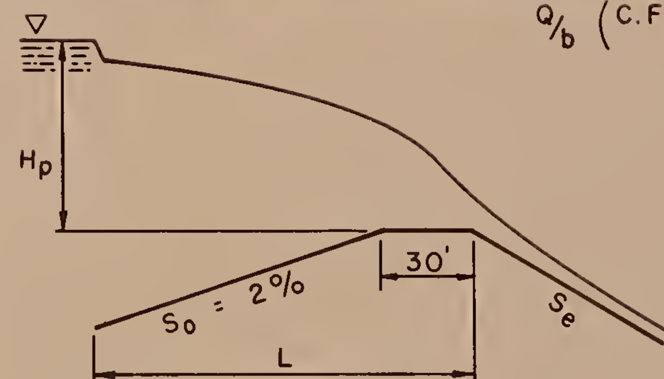
Values in Table are Q/b – C.F.S./Ft.

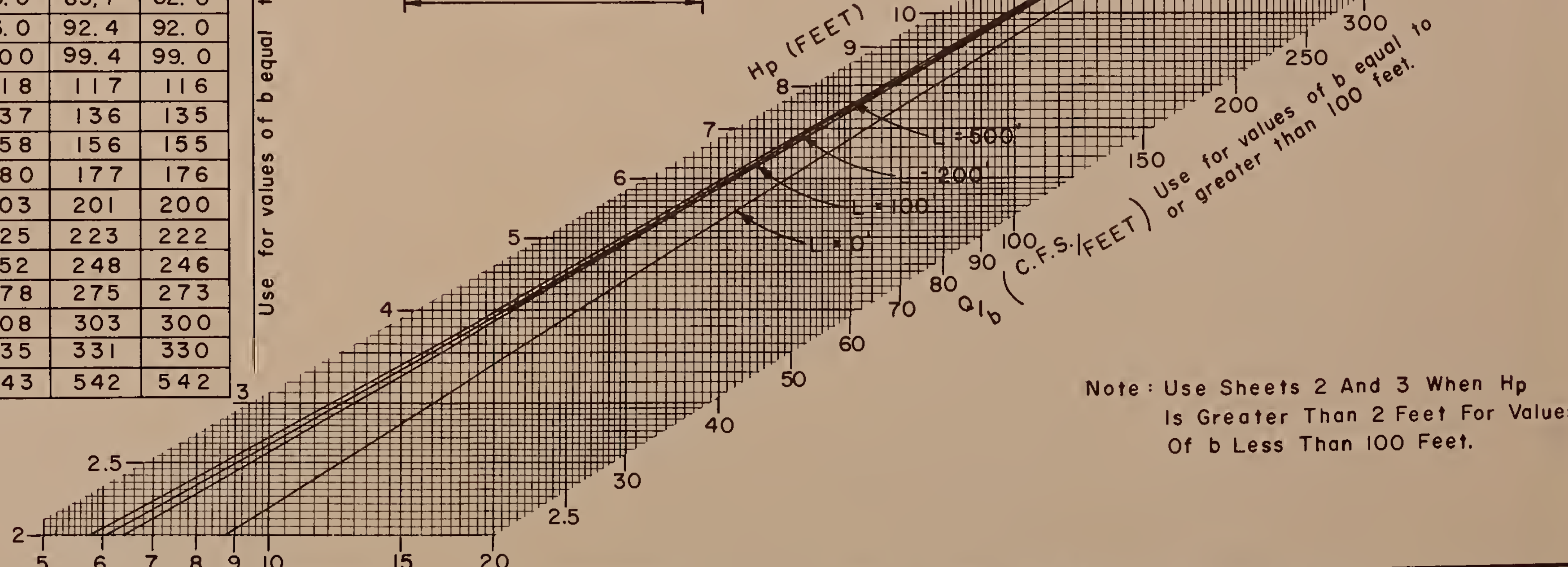
| Hp-Ft. \ L-Ft. | 0 | 100 | 150 | 200 | 300 | 500 |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.5 | 1.10 | 0.58 | 0.57 | 0.56 | 0.54 | 0.53 |
| 1.0 | 3.12 | 1.94 | 1.90 | 1.88 | 1.81 | 1.77 |
| 1.5 | 5.70 | 3.92 | 3.81 | 3.74 | 3.62 | 3.54 |
| 2.0 | 8.78 | 6.40 | 6.22 | 6.10 | 5.92 | 5.80 |
| 2.5 | 12.5 | 9.5 | 9.20 | 9.00 | 8.87 | 8.78 |
| 3.0 | 16.5 | 13.0 | 12.7 | 12.5 | 12.3 | 12.2 |
| 3.5 | 21.2 | 17.0 | 16.7 | 16.5 | 16.3 | 16.2 |
| 4.0 | 26.2 | 21.2 | 20.9 | 20.8 | 20.5 | 20.4 |
| 4.5 | 31.4 | 26.0 | 25.7 | 25.5 | 25.1 | 24.8 |
| 5.0 | 37.0 | 31.0 | 30.9 | 30.8 | 30.2 | 29.8 |
| 5.5 | 43.2 | 37.0 | 36.4 | 36.0 | 35.4 | 35.0 |
| 6.0 | 50.0 | 42.0 | 42.4 | 41.0 | 41.4 | 40.5 |
| 6.5 | 56.5 | 49.5 | 48.6 | 48.0 | 47.1 | 46.5 |
| 7.0 | 63.2 | 55.0 | 55.1 | 54.0 | 53.6 | 53.0 |
| 7.5 | 71.0 | 63.0 | 62.4 | 62.0 | 61.1 | 60.5 |
| 8.0 | 78.5 | 69.0 | 69.7 | 68.0 | 68.6 | 67.0 |
| 8.5 | 87.0 | 78.0 | 77.4 | 77.0 | 75.8 | 75.0 |
| 9.0 | 95.5 | 85.5 | 85.4 | 83.0 | 83.7 | 82.0 |
| 9.5 | 104 | 94.0 | 93.4 | 93.0 | 92.4 | 92.0 |
| 10.0 | 113 | 103 | 101 | 100 | 99.4 | 99.0 |
| 11.0 | 132 | 120 | 119 | 118 | 117 | 116 |
| 12.0 | 152 | 138 | 137 | 137 | 136 | 135 |
| 13.0 | 174 | 160 | 159 | 158 | 156 | 155 |
| 14.0 | 195 | 182 | 181 | 180 | 177 | 176 |
| 15.0 | 220 | 205 | 204 | 203 | 201 | 200 |
| 16.0 | 245 | 227 | 226 | 225 | 223 | 222 |
| 17.0 | 277 | 255 | 253 | 252 | 248 | 246 |
| 18.0 | 298 | 280 | 279 | 278 | 275 | 273 |
| 19.0 | 328 | 310 | 309 | 308 | 303 | 300 |
| 20.0 | 355 | 340 | 337 | 335 | 331 | 330 |
| 26.0 | 562 | 545 | 544 | 543 | 542 | 542 |

Use for all values of b. (Hp 0 to 2.0)

Use for values of b equal to or greater than 100 feet. (Hp 2.5 to 26.0)




Note: Use Sheets 2 And 3 When Hp Is Greater Than 2 Feet For Values Of b Less Than 100 Feet.

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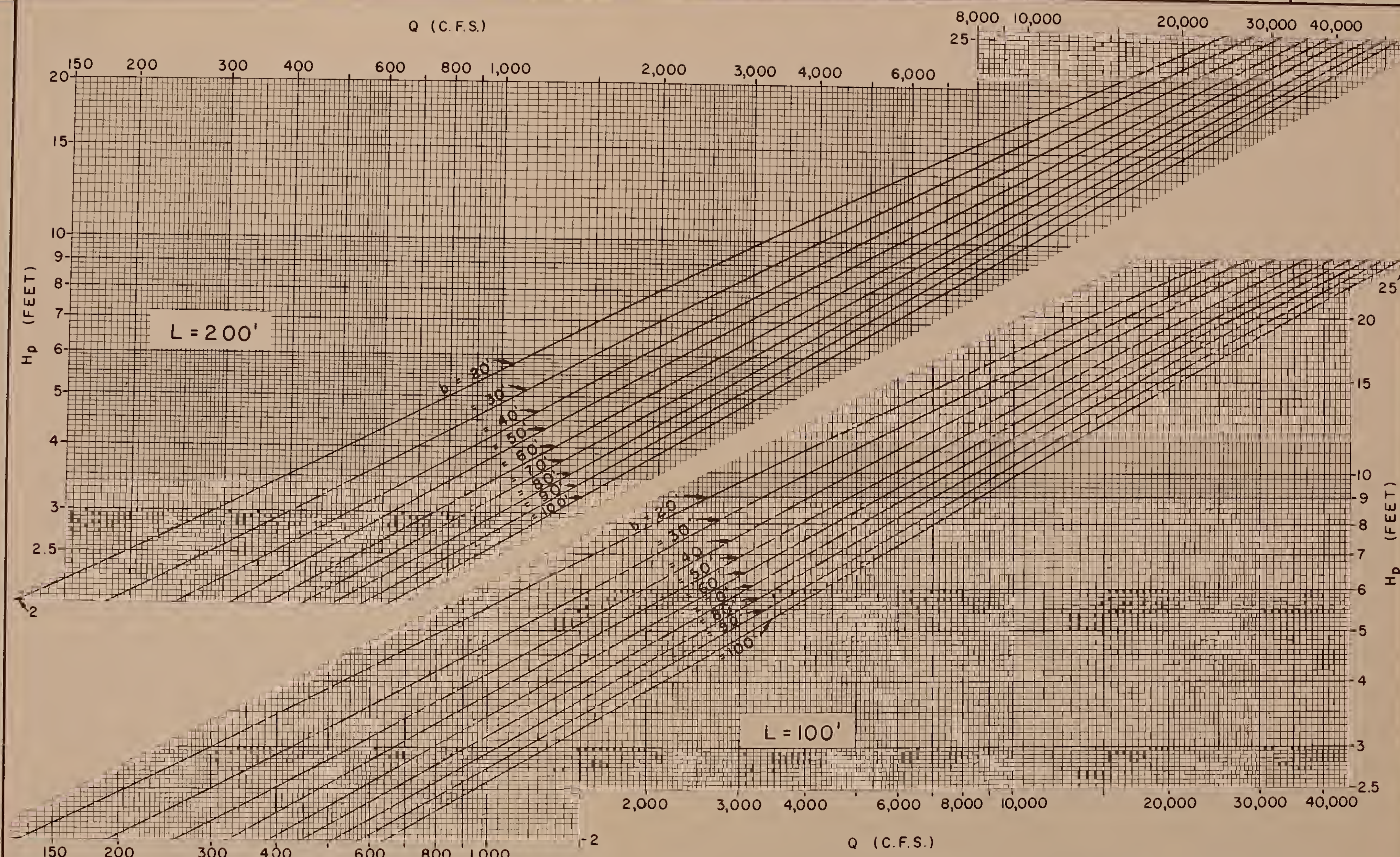
STANDARD DWG. NO. ES-611
SHEET 1 OF 3
DATE Jan. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

Z = 2½

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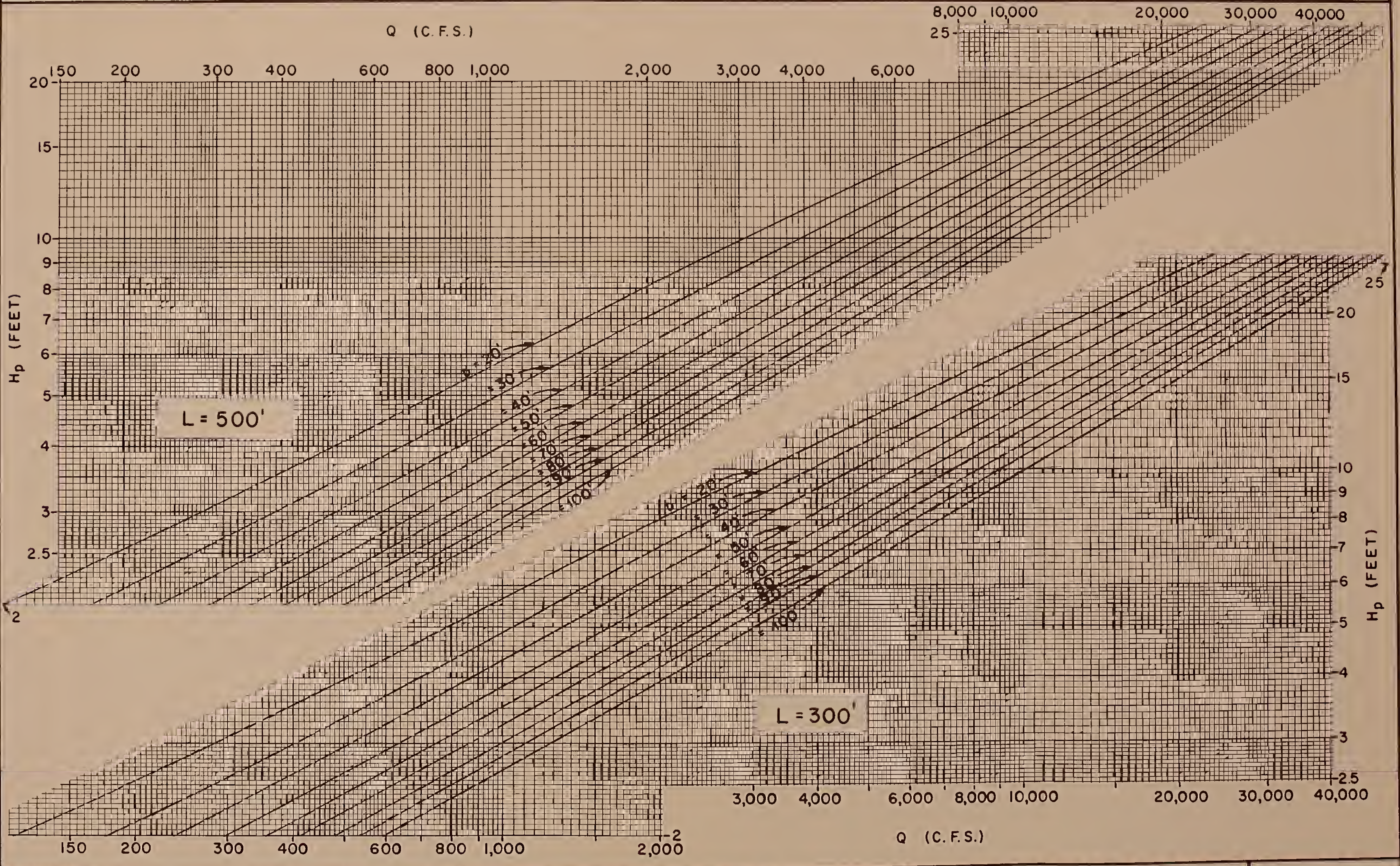
STANDARD DWG. NO.
ES - 611
SHEET 2 OF 3
DATE Jan. 1966

UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

Z = 2½

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ES - 611
SHEET 3 OF 3
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USDA-SCS-HYATTSVILLE, MD. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

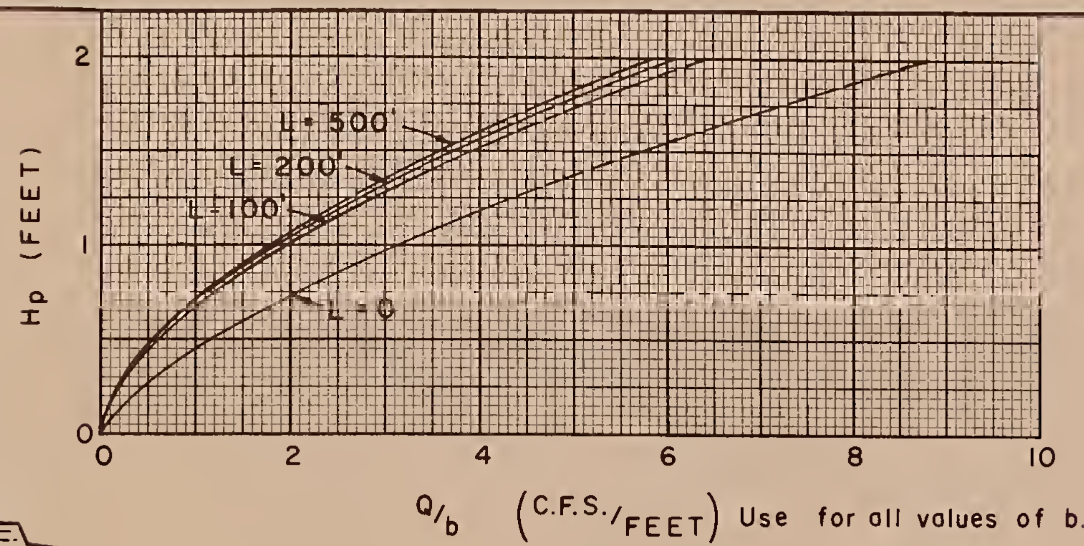
Z = 3

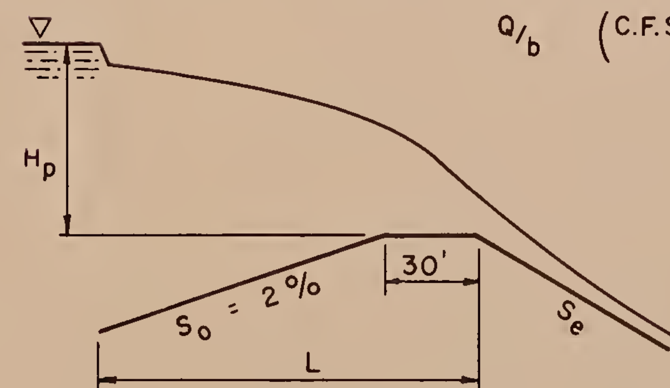
Values in Table are $Q/b$ – C.F.S./Ft.

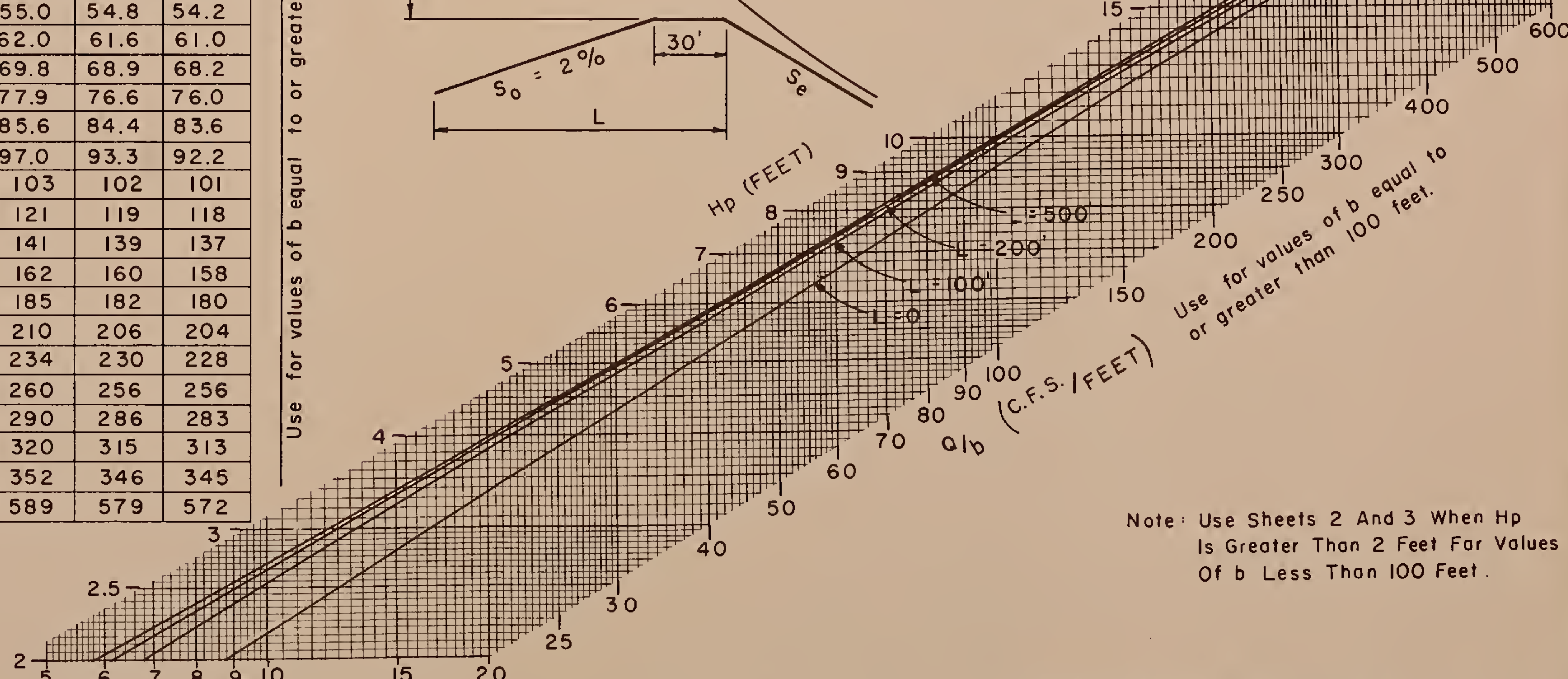
| Hp Ft. \ L-Ft. | 0 | 100 | 150 | 200 | 300 | 500 |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.5 | 1.10 | 0.58 | 0.57 | 0.56 | 0.54 | 0.53 |
| 1.0 | 3.12 | 1.94 | 1.90 | 1.88 | 1.81 | 1.77 |
| 1.5 | 5.70 | 3.92 | 3.81 | 3.74 | 3.62 | 3.54 |
| 2.0 | 8.78 | 6.40 | 6.22 | 6.10 | 5.92 | 5.80 |
| 2.5 | 12.6 | 9.78 | 9.22 | 9.05 | 8.83 | 8.68 |
| 3.0 | 16.7 | 13.2 | 12.7 | 12.5 | 12.3 | 12.2 |
| 3.5 | 21.6 | 17.2 | 16.7 | 16.4 | 16.2 | 16.0 |
| 4.0 | 26.6 | 21.5 | 21.1 | 20.6 | 20.4 | 20.2 |
| 4.5 | 32.0 | 26.4 | 25.9 | 25.5 | 25.1 | 24.9 |
| 5.0 | 37.8 | 31.7 | 31.2 | 30.8 | 30.3 | 30.0 |
| 5.5 | 44.1 | 37.4 | 36.7 | 36.2 | 35.7 | 35.4 |
| 6.0 | 50.7 | 43.6 | 42.8 | 42.2 | 41.7 | 41.3 |
| 6.5 | 58.0 | 50.0 | 49.3 | 48.5 | 48.2 | 47.8 |
| 7.0 | 64.9 | 56.8 | 56.2 | 55.0 | 54.8 | 54.2 |
| 7.5 | 73.0 | 64.0 | 43.0 | 62.0 | 61.6 | 61.0 |
| 8.0 | 80.2 | 71.6 | 70.5 | 69.8 | 68.9 | 68.2 |
| 8.5 | 89.5 | 79.0 | 78.7 | 77.9 | 76.6 | 76.0 |
| 9.0 | 98.0 | 87.8 | 86.5 | 85.6 | 84.4 | 83.6 |
| 9.5 | 107 | 96.8 | 95.7 | 97.0 | 93.3 | 92.2 |
| 10.0 | 117 | 106 | 104 | 103 | 102 | 101 |
| 11.0 | 137 | 124 | 122 | 121 | 119 | 118 |
| 12.0 | 159 | 145 | 142 | 141 | 139 | 137 |
| 13.0 | 183 | 166 | 164 | 162 | 160 | 158 |
| 14.0 | 208 | 190 | 187 | 185 | 182 | 180 |
| 15.0 | 234 | 214 | 212 | 210 | 206 | 204 |
| 16.0 | 261 | 241 | 237 | 234 | 230 | 228 |
| 17.0 | 290 | 268 | 263 | 260 | 256 | 256 |
| 18.0 | 321 | 297 | 293 | 290 | 286 | 283 |
| 19.0 | 356 | 330 | 324 | 320 | 315 | 313 |
| 20.0 | 390 | 364 | 357 | 352 | 346 | 345 |
| 26.0 | 636 | 602 | 594 | 589 | 579 | 572 |

Use for all values of b. (Hp 0 – 2.0)

Use for values of b equal to or greater than 100 feet. (Hp 2.5 – 26.0)




Note: Use Sheets 2 And 3 When Hp Is Greater Than 2 Feet For Values Of b Less Than 100 Feet.

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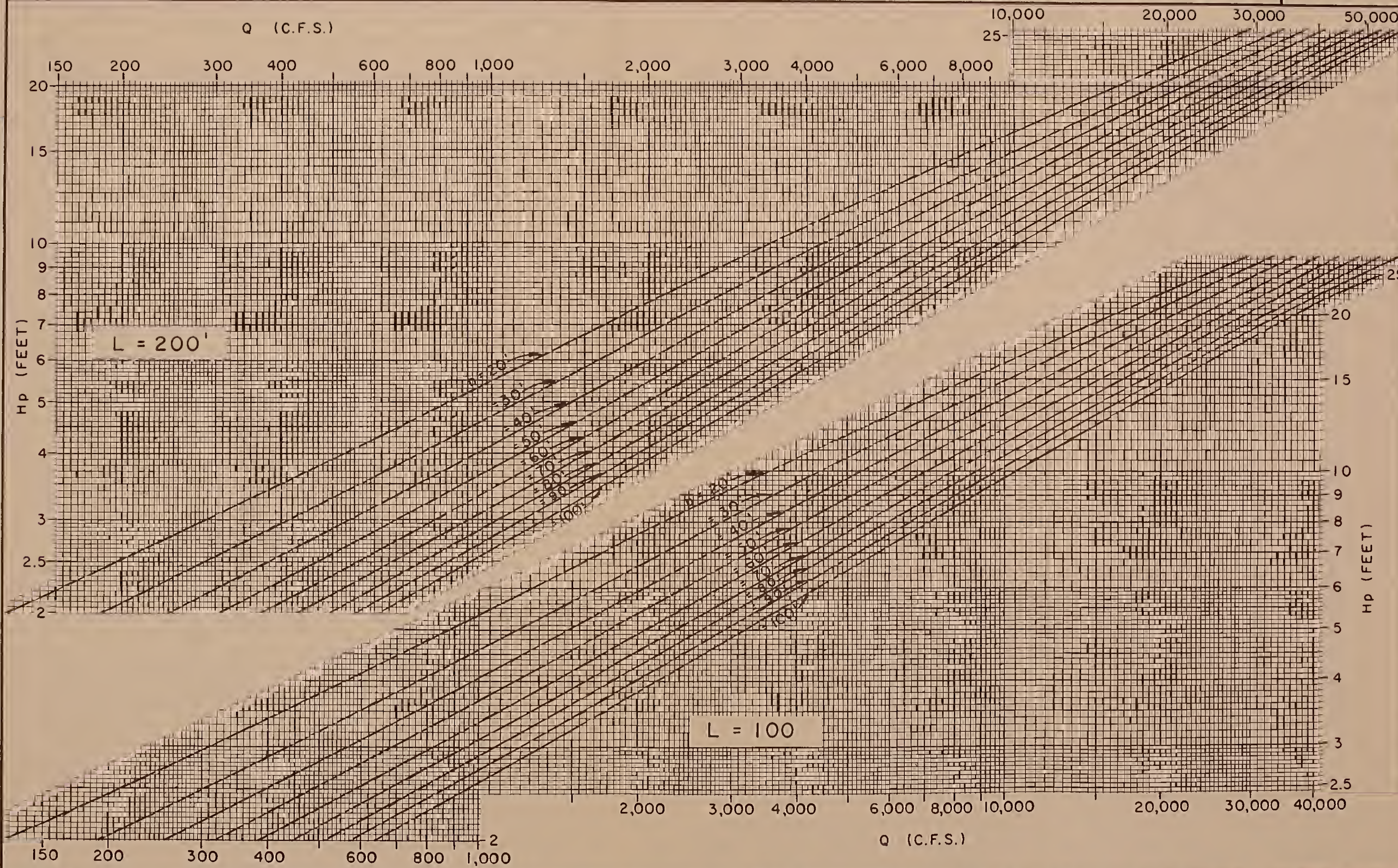
STANDARD DWG. NO. ES - 612
SHEET 1 OF 3
DATE Jan. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

Z = 3

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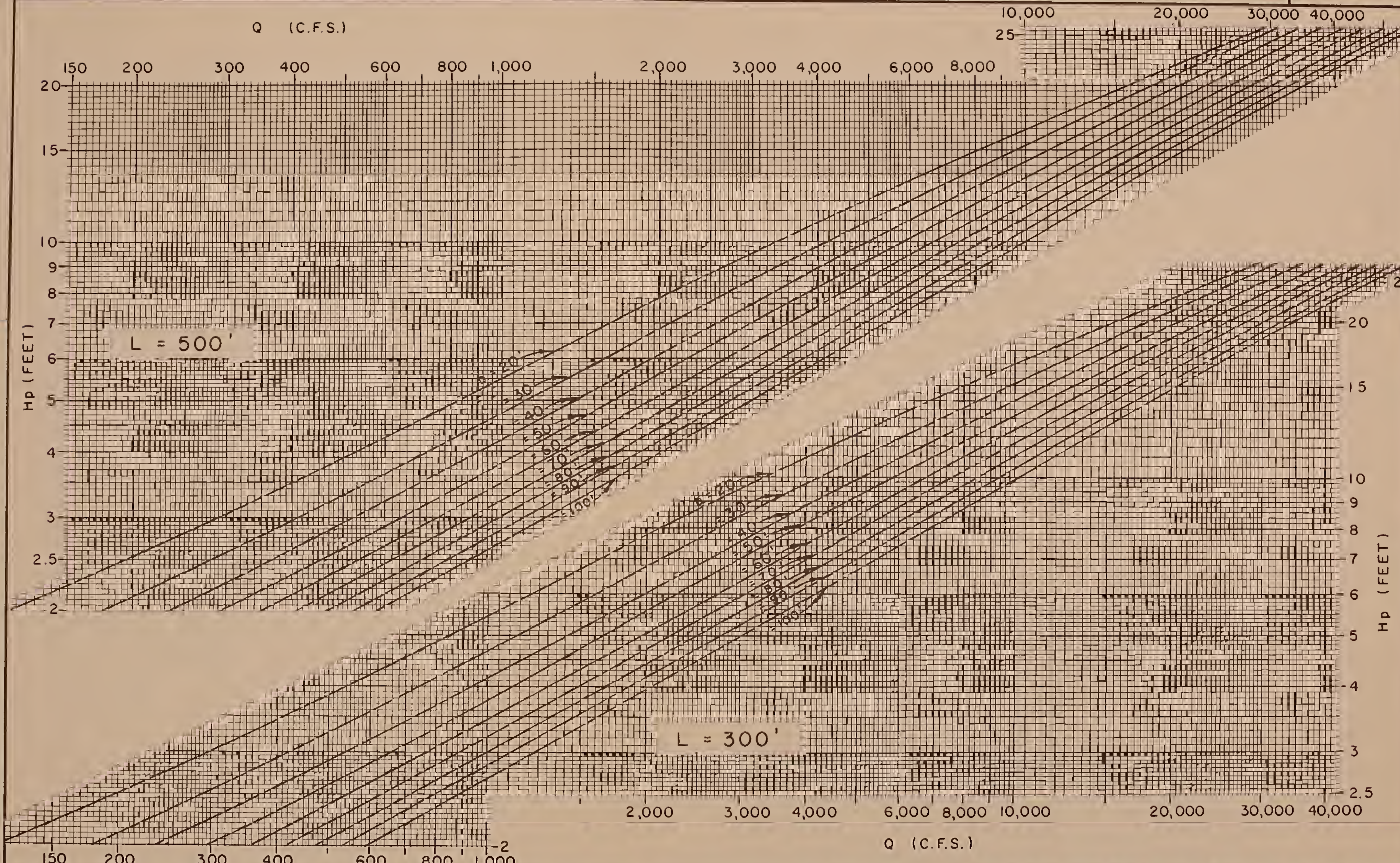
STANDARD DWG. NO.
ES-612
SHEET 2 OF 3
DATE Jan. 1966

# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

Z = 3

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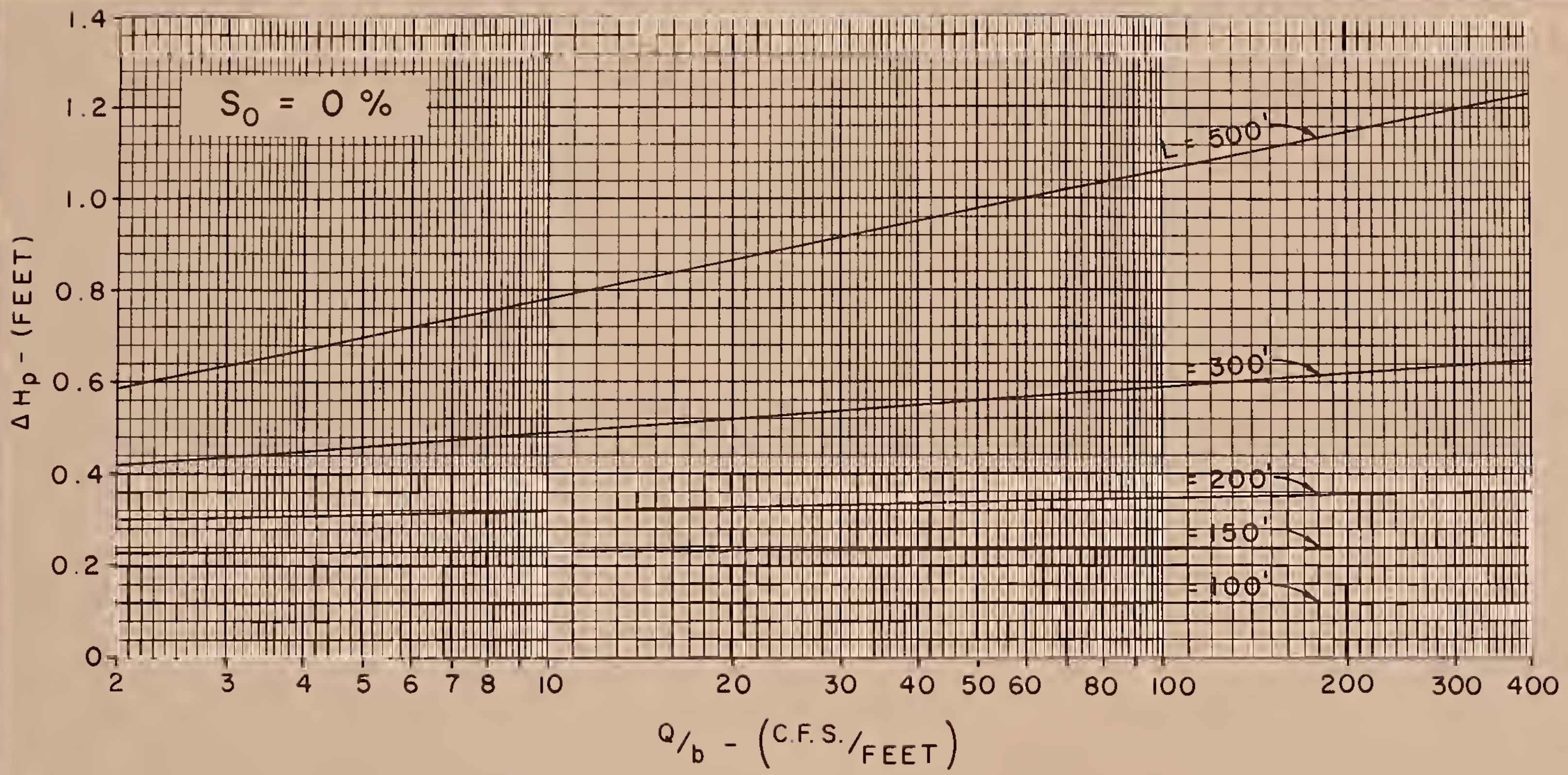
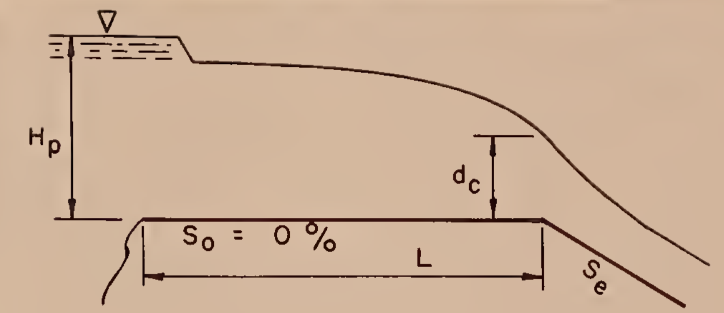
ES - 612
SHEET 3 OF 3
DATE Jan. 1966

USDA-SCS-HYATTSVILLE, MD. 1966

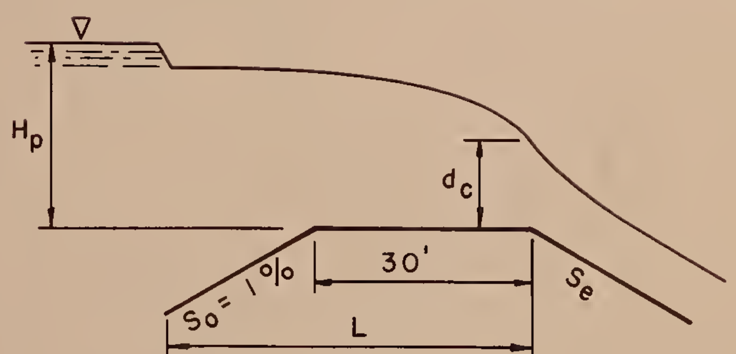
# UD METHOD: EMERGENCY SPILLWAY HYDRAULICS, DISCHARGE CHARTS

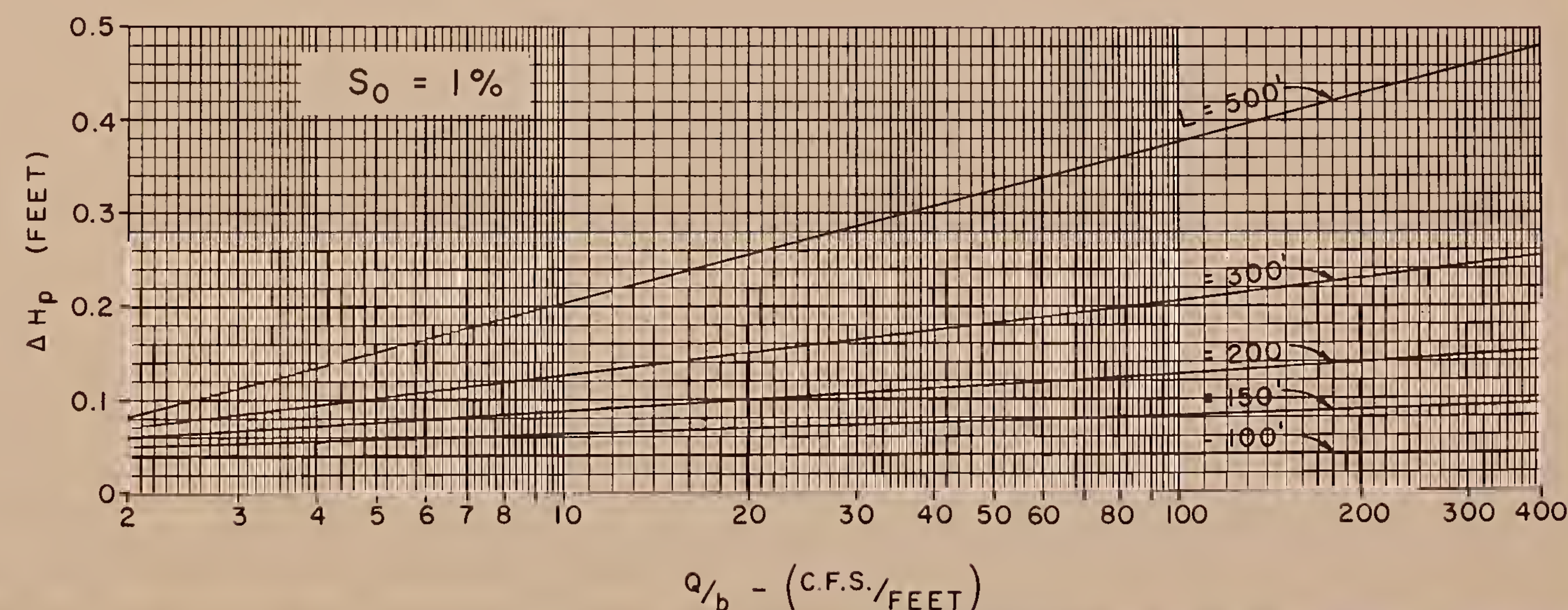
$\Delta H_p$




$\Delta H_p$ = Value to be added to $H_p$ values obtained from ES-606 to ES-612 to adjust for entrance slope ($S_o$) of 0% and 1%.

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